ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA/AZ 86/197

THE TECHNICAL FEASIBILITY, SOCIO-ECONOMIC IMPACT AND ENVIRONMENTAL BENEFITS OF ALTERNATE ENERGY VEHICLES AS RELATED TO THE STATE OF ARIZONA

Volume 1: Technical Summary
Final Report

Prepared by:
Kenneth J. Saczalski, Ph.D.
Lanny J. Mullens, Ph.D.
College of Engineering and Technology
Janet Schnorr, Ph.D.
College of Social and Behavioral Sciences
James F. Morgan, Ph. D.
College of Business Administration
Northern Arizona University
Flagstaff, Arizona 86011

August 1986

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

TECHNICAL REPORT DOCUMENTATION PAGE

1. REPORT NO. HPR-PL-1(31) Item 197	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE The Technique Feasibility, Socioeconomic Impact and Environmental Benefits of Alternate Energy Vehicles in the State of Arizona		5. REPORT DATE August 1986 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Ken Saczalski, Janet Schnorr Lanny Mullens, James Morgan		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Northern Arizona University College of Engineering and Technology Flagstaff, Arizona		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. 13. TYPE OF REPORT & PERIOD COVERED
12. SPONSORING AGENCY NAME AND ADDRESS Arizona Transportation Research Center Arizona Department of Transportation		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This study analyzes the potential market penetration in Arizona of various types of alternate energy vehicles. This market penetration is analyzed in terms of changes in the price of fuel, tax incentives, costs of conversion and consumer attitudes.

While the study analyzes data only through 1985, many conclusions and responses related to the previous rapid rise in fuel prices may be relevant in light of the rapid price increases of early 1987.

Short term market penetration, in the absence of legal intervention, is expected to amount to a very small fraction of the total operating fleet of motor vehicles.

17. KEY WORDS	18. DISTRIBUTION STATEMENT No restrictions.

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES 428	22. PRICE

TABLE OF CONTENTS

VOLUME I

Technical Summary

SECTION				PAGE
ABSTRACT				ii
ACKNOWLEDGEMENTS				iii
1.	BACKGROUND			1
	1.1	The Beginning (1981): Energy Availability/Costs and Pollution Concerns		1
	1.2	The Basic Problem: A Multi-Disciplinary Approach		2
	1.3	Goals and Objectives		4
	1.4	Research Approach		7
2.	AE TECHNOLOGICAL FEASIBILITY			30
	2.1	Energy Availability: Some Possible Future Scenarios		30
	2.2	Alternate Energy Transportation Systems		42
		2.2.1	Electric and Hybrid Electric: A Dark Horse AE System for Arizona	43
		2.2.2	Feasibility of AE Transportation System for Arizona	47
		2.2.3	CNG: The Most Promising AE Alternative for Arizona	56
			2.2.3a Home Unit (Slow Fill) CNG Supply	65
			2.2.3b Dual Fuel Capacity	67
			2.2.3c Dual Fuel Conversion Costs	68
	2.3	Hydrogen as a Possible Future AE System		71
	2.4	Costs, Safety and Emission Benefits of the Most Likely AE Systems		76
		2.4.1	Fuel Savings	78
		2.4.2	Federal, State and Local Regulations	79
		2.4.3	Environmental Concerns	80
		2.4.4	Vehicle Comparison	82
		2.4.5	Summary	87

SECTION		PAGE
3.	SOCIO-BEHAVIORAL CHARACTERISTICS	88
	3.1 Introduction	88
	3.1.1 Theoretical Orientation	88
	3.1.2 Assumptions	91
	3.2 Survey Approach	93
	3.3 Regression Analysis	122
	3.4 Factor Analysis of Mall Survey Data Factors	125
	3.4.1 Procedure	125
	3.4.2 Limitations of the Data	126
	3.4.3 Results	126
4.	AE FUEL TAXES/INCENTIVES AND LPG/CNG MARKETS	138
5.	SUMMARY OF ESTIMATES OF DEMAND FOR AND MARKET PENETRATION OF ALTERNATIVELY FUELED VEHICLES IN ARIZONA	148
6.	A SURVEY OF PROSPECTIVE CONSUMER DEMAND FOR ALTERNATIVELY FUELED VEHICLES	159
	6.1 Methodology	161
	6.1.1 Survey Objectives	161
	6.1.2 Review of Literature	162
	6.1.3 Survey Design	167
	6.2 Demographic Characteristics of Survey Respondents	176
	6.3 Survey Respondent's Reactions to AE Vehicles	179
	6.4 Analysis of Variance Results	219
7.	ESTIMATES OF AE FUELED VEHICLE MARKET PENETRATION UNDER VARIOUS SUPPLY SCENARIOS	250
	7.1 Supply Scenarios	251
	7.2 The Vehicle Purchase Decision	255
	7.3 Logit Analysis of Scenario and Survey Data	257
	7.4 Predicted AV Penetration Rates	264
8.	NAU ALTERNATE FUEL REVENUE SIMULATION PROGRAM	269
	8.1 Introduction	269
	8.2 Model Design	271
	8.3 Model Input	273
	8.3.1 Regression Coefficients	273
	8.3.2 CNG Technology	279
	8.3.3 Innovation Level	281
	8.3.4 Fleet Characteristics	282

SECTION		PAGE
	8.4 Program NAUFC	283
	8.5 Examples of NAUFC Prediction for Various Scenarios	284
9.	CONCLUSION & RECOMMENDATION	289
10.	REFERENCES	291
	APPENDIX A - Transportation Survey - Flagstaff Mall (1984)	295
	APPENDIX B - Transportation Survey - Tucson & Phoenix Malls	350
	APPENDIX C - Vehicle Demand Survey Questionnaire: Non-Rationing	418
	APPENDIX D - Vehicle Demand Survey Questionnaire: Rationing	421

ACKNOWLEDGEMENTS

The authors of this report wish to acknowledge and sincerely thank Mr. William Sapper (Project Manager/ATRC) and Mr. Hari Khanna (Project Technical Supervisory Committee Chairman/ADOT) for their support provided throughout the course of this study. In addition, we are most thankful for the outstanding technical guidance and insight on alternate energy issues, perspectives and costs, provided by Dr. William M. Brown of the prestigious Hudson Institute. Thanks are also due to Mr. Robert Rasins of the Southwest Gas Corporation for his assistance in the CNG technical and cost areas, and Dr. Takeshi Yoshihara of the state of Hawaii Energy Office for his insight on consumer attitutes toward alcohol blends. Numerous other individuals have also contributed to the success of this project and they include: Dr. Vadim Kopytoff (currently Staff Scientist with McDonnell Douglas Aircraft Co., and formerly with the Lawrence Livermore Laboratory and the Northern Arizona University); Dr. Roberta J. Nichols (Research Staff of the Ford Motor Company); Messrs. David and Dan Zavaleta (design, fabrication, and field testing of a hydrogen powered automobile), Messrs. Mark West and Robert Skow (Electric Vehicles and Natural Gas Alternate Energy Systems); (Computer Assistance in Development of an Alternate Energy Demand Forecast Model); Mrs. Pennie Seibert (Socio-behavioral surveys and field studies); Mr. Michael Levick (Statistical evaluation of socio-behavioral and marketing/economics field data); Members of the NAU/ADOT Research Project Technical Supervisory Committee- Messrs. Jim Grady (Salt River Project), Bernie Dean (Motor Vehicle Division of ADOT), Russ Jakes (ADOT), Dan Miller (Highway Users Federation), and Dan Schein (Office of the Governor); and Mrs. Patricia Sprouse for her patience in handling the day to day chores of meetings coordination and numerous secretarial duties, including the typing of this report.

SECTION 1

BACKGROUND

1.1 THE BEGINNING (1981): ENERGY AVAILABILITY/COSTS AND POLLUTION CONCERNS.

The genesis for this particular study on Alternate Energy (AE) Transportation Systems started with a request for proposal (RFP), issued in late 1981 by the Arizona Transportation Research Center (ATRC), to study the effect of electric vehicles and AE transportation systems influx on highway revenue funds and pollution reduction in the state of Arizona. In part, the 1981 interest in studying the impact of AE systems and electric vehicles was driven by the seemingly "ever-increasing" costs of gasoline. In the three year span from 1978 to 1981 the average United States Labor Day price of gasoline (averaged for all types of gasoline) virtually doubled from approximately 69 cents per gallon to a price of $1.37 per gallon. At that time (1981) there seemed to be little doubt that gasoline costs would continue to rise (at a modest rate at best), petroleum energy supplies would diminish and pollution problems would continue to increase in the urban/metropolitan regions of the United States. Technical, economic, and marketing research studies conducted around 1980 to early 1982 on the commercial feasibility [1] * and potential demand for electric vehicles [2,3] suggested that the electric

---

*Note: Numbers in brackets designate references listed at the end of report.

vehicle, and other forms of AE transportation systems [4], offered a promising alternative to the petroleum consumption and pollution problems of the internal combustion engine (ICE) vehicles. Consumers seemed to be aware of the energy problem and energy conservation was becoming fashionable, as evidenced by the energy consumption data shown in Figures, 1-1 and 1-2 taken from reference 5.

In late March of 1982, Northern Arizona University (NAU) responded to the ATRC request for proposals related to Electric Vehicles and Alternate Energy Systems. Approximately a year and one-half later (i.e. November, 1983) NAU was awarded a contract (ADOT Contract No. 83-86) from the Arizona Department of Transportation (ADOT) to perform a two-year study on "The Technological Feasibility and Socio-Economic Impact of Alternate Energy Vehicles as related to the state of Arizona". The research project (No. HPR-1(28) item 197) was administered by the ATRC.

1.2 THE BASIC PROBLEM: A MULTI-DISCIPLINARY APPROACH

The 1981 problem of increasing petroleum costs has, at least temporarily, diminished as a major force of influence likely to cause consumer adoption of AE transportation technology. During the approximately 2 year time span from the RFP concept of this study (late 1981) to the time of the contract award (late 1983) the average costs of gasoline fell approximately 10 cents per gallon, with the current prices of gasoline dropping even farther, to about 90 cents per gallon, as shown by Figure 1-3. The results of this study, however, have shown that consumers likely to purchase AE vehicles do not consider the price of fuel as a key factor in adopting a new technology.

For several reasons, the rapidly growing urban areas of Phoenix and Tucson, Arizona, seem to have good potential for alternate energy vehicle markets. First, both areas are faced with increasing pollution problems and loss of federal revenues for air quality violations. Air quality standards during Winter of 1985-86 were violated in both Phoenix and Tucson. The Arizona population tends to be acutely aware of air pollution (and violations) and is willing to take positive steps to control it. Next, Arizona's abundant coal reserves, hydroelectric power, nuclear power, and broad distribution network for home-heating natural gas offer the potential for some near term (5 to 15 years away) alternatives to the pollution problems created by standard internal combustion engine vehicles. Unfortunately, concomitant with the pollution (and perhaps long term cost) advantages of the Alternate Energy Transportation systems there is the basic problem that highway revenue badly needed for repair and new roads would diminish from the traditional source of gasoline taxes if the use of gasoline were reduced through the penetration of a significant number of AE vehicles into the Arizona vehicle market if taxation alternatives were not implemented.

This study examined the above basic problem by means of an interdisciplinary approach. First, the socio-psychological characteristics of consumer lifestyles in Arizona were examined and evaluated relative to susceptibility for change, as related to behavioral attitudes which would influence the marketing of, or lack of interest in, electric, hybrid electric or other alternative technology vehicles. Next the technological feasibility of AE vehicles and associated costs were integrated into a marketing/socio-economic demand study to determine which trends and factors were most likely to impact the level of AE vehicle market penetration in Arizona. The above factors were combined with various fuel/vehicle scenarios and costs (i.e. crisis situation, rationing, no-rationing, etc.) and used in the development of a AE vehicle market penetration forecast model for the state of Arizona. The forecast model was designed to enable parametric studies on various AE vehicle fee schemes and incentives to enable ADOT management to assess what types of fee approaches and policies would best suit the joint economic and environmental needs of the state, the utility companies, and the consumer. Figure 1-4 illustrates a schematic of how the multi-disciplinary areas and study results were integrated into the NAU forecast model. The figure also identifies the respective project directors for each of the primary research areas.

1.3 GOALS AND OBJECTIVES

The primary goal of this research project was to develop an Alternate Energy Vehicle (AEV) forecast model which would enable ADOT management to:

1) Estimate potential highway revenue loss (if any) due to penetration of AEV's;

2) Evaluate possible user fee schemes for recovery of lost highway revenue; and

3) Make technically sound policy decision and legislative recommendations relative to taxation of AEV systems.

In order to achieve the primary goal of this research effort it was necessary that certain key issues and basic data be identified and examined in the areas of socio-behavioral sciences, economics and demand penetration of AEV systems, AEV technology/costs and infra-structure, and systems modeling. A summary of the key objectives in each of the above areas are as follows:

A. Behavioral Study Objectives:

1. Identify the attitude and behavioral characteristics of AEV users and non-users. (Data indicates that most multi-car families are more affluent, but the most affluent or middle/upper classes are not really motivated to adopt alternative technologies. The less affluent young and elderly classes are more likely to consider alternate technologies);

2. Assess the current level of public knowledge about electric vehicles and other alternate energy systems such as compressed natural gas and propane powered vehicles.

3. Identify the advantages and disadvantages (real and

imagined) of alternate technologies for transportation.

B. Technology Study Objectives:

1. Identify the most likely forms of alternate energy vehicle systems for the immediate (0 to 5 years away), near term (5 to 15 years away), and for long term (15 to 25 years away) time frames;

2. Estimate the costs to consumers for the most likely AEV systems;

3. Review alternate energy key issues likely to result in fluctuations in petroleum and natural gas prices;

4. Estimate energy availability and possible AE use scenarios for input to the economics/demand penetration study and the Forecast model.

C. Economic/Demand Penetration Study Objective:

1. Identify key economic factors and other related system parameters which can be measured currently and then be used to specify forecasting and/or prediction models suitable for estimating demand for AE vehicles.

2. Evaluate the demand/penetration effects of various differences relative to conventional ICE vehicles such as higher costs for AEV's, limited range, lower pollution, lower operating costs, etc.;

3. Coordinate with the behavioral studies group to adjust as appropriate the demand/penetration likelihood based on user/consumer preferences and attitudes.

D. Systems Modeling Study Objective:

1. Identify the key modeling parameters associated with the behavioral study, economics/marketing penetration study, and the AEV technology study;
2. Integrate the findings of the various study groups to develop an interdisciplinary forecasting and/or prediction model to enable ADOT to investigate the likelihood of AEV market penetration into the state of Arizona and also allow assessment of certain user fee schemes;
3. Investigate the sensitivity of the model to changes in the operating environment (i.e. variations in parameters);
4. Assess the ability of the model to make reasonable predictions;
5. Develop and document the model, and the resulting computer code, in such a manner as to make it useful to ADOT personnel (i.e. have simplified desk top personal computer version of the code along with the larger main frame version and write the code in a language(s) that makes it easily portable;
6. Provide a user seminar to ATRC and ADOT personnel.

1.4 RESEARCH APPROACH

In developing a model to assess the impact of alternative fuels, the NAU team of investigators reviewed extensive literature and research which dealt with 1) descriptions of alternative fuel scenarios and fuel crises, 2) expert's predictions of likely alternative fuels, and 3) cost/benefit studies related to alternative fuel projects. Many of these studies have used computer models based on data extrapolated from experts or based on a limited number of interviews with consumers. In some cases, models were developed to predict the feasibility of mass production of selected technologies. Most of the forecasts indicate limited potential for alternative vehicles. For example, electric vehicles are perceived as having a limited range, lengthy refueling, limited performance, and limited load carrying capability. These factors negatively impact the development of mass production for the general consumer or private market and are well articulated in the research. Consumer behavior, attitudes, knowledge, misconceptions and preferences were not included in the above studies.

Discussions held with electric vehicle manufacturers and the NAU research team [6] reinforces the importance of the role of human factors in this interdisciplinary study. For instance, a lack of knowledge of the consumer attitudes (either conscious or subconscious) related to what the consumer expects to see when looking under the hood of an electric vehicle, or what fears and apprehensions (real or imagined) the consumer may have regarding servicing, repair-ability and trade-in value of an AEV may represent a major block to the successful marketing of AEV's in the state of Arizona, in spite of the many attractive features of

AEV's when considering environmental and energy factors. Issues such as energy availability, costs, technical performance and comfort and convenience, as well as safety, are also important AEV marketing considerations.

The NAU AE research team felt that the above behavioral factors could provide valuable input for a more accurate model of demand penetration of AEV's into the state of Arizona and, subsequently, a more accurate forecast model of fuel consumption. Therefore, extensive demographic research was undertaken, through the use of personal interviews and surveys, to model an average driver. This demographic information was obtained to 1) develop a profile of the average driver in Arizona, and 2) to make comparisons between Arizona samples and national statistics. The socio-behavioral surveys were made by direct contact with consumers at malls or shopping areas in Flagstaff, Phoenix and Tucson. The NAU research team set up an alternate energy display complete with a working electric vehicle and a hydrogen powered vehicle or CNG vehicle. Consumers were attracted to the vehicles and expressed willingness to complete the entire survey questionnaires illustrated in appendices A and B. The Flagstaff survey was conducted first as a trial run and, based upon the consumer response, the survey questionnaire was then modified slightly for use in the Phoenix and Tucson areas. Details of the socio-behavioral characteristics of Arizona drivers are presented in section 3 of this report.

By using the research from the social and behavioral sciences it is possible to gain a fundamental understanding of the assumptions, and possible misperceptions used by a consumer during the purchase or rejection of a new or innovative technology. For example, several years ago, the state of Hawaii tried to encourage "gasohol" consumption with the intent that local sugar cane industries could supply the alcohol thus reducing the states heavy dependence on oil or petroleum imports [7]. Originally gasohol (a mixture of about 10% alcohol, such as methanol, with 90% gasoline) created certain problems with standard vehicle designs (such as drying out of seals and subsequent leaking of fuels) and appropriate warnings were issued to consumers. The negative impact of these warnings persisted and affected consumption. In an attempt to overcome these negative impacts, several companies changed the "gasohol" label to "high octane booster". The label change coupled with a <u>reduced state sales tax incentive</u> on the "high octane booster" fuel resulted in greatly improved consumer usage in the state of Hawaii [7]. A similar trend is occurring in the mainland United States. For whatever reason, the label "gasohol" does have a negative impact on consumers whereas "high octane" does not.

Market or <u>demand penetration</u> of AE vehicles seems to be affected by similar consumer attitudes and misperceptions. As a result, the market or demand penetration study of this project also used a consumer type of survey to determine: 1) key buying trends; 2) willingness to purchase AEV's; and 3) likely <u>percent of penetration</u> of AEV's into the state of Arizona. Past similar studies [8, 9, 10] have looked at consumers in general and the results have very limited reliability to the Arizona market. This study focused on the target groups most likely to adopt the technology, with the assumption that other segments of the Arizona population will follow the behavior of these groups if price and performance meet the expectations of the public.

The market or vehicle demand survey was designed to provide quantitative estimates of the value Arizona consumers place on various vehicle attributes. This information was then used to determine the threshold price at which various consumers would be willing to switch to alternately fueled vehicles of a variety of alternate types. The primary output of the demand/marketing survey was a statistical result (analysis of variance) which was used to evaluate the relative importance of various vehicle attributes to consumers. This data was helpful in determining which of the wide variety of possible alternative technologies was most plausible to the residents of Arizona. In addition the statistical results provided the basis for estimates of the market penetration of various alternate technologies under given scenarios. To support such estimates the scenarios had to specify selling prices and fuel costs of each vehicle configuration.

Data on AE vehicle types, costs for new or converted designs, fuel/energy economy data, fuel/energy costs, likely performance data, and future scenario data based on likely energy availability of AEV systems were supplied by the AE technology study section of this report. Details of the AE technology study are contained in section 2 of this report. Figure 1-5 illustrates the close integration of the technological, social-behavioral, and marketing/demand penetration studies with the NAU Forecast model development.

The vehicle demand survey was administered to various service groups in conjunction with a 30 minute technical slide presentation designed to familiarize the survey audience with the potential alternate vehicle technologies. It was felt that such a presentation was necessary in order to develop knowledge among respondents sufficient to provide reasonable data. It should be noted that the social-behavioral survey study tested respondents to ascertain their level of knowledge about AEV systems without the benefit of a technical presentation (the socio-behavioral survey study did however use a display of AE vehicles to attract consumers to the survey area). Figure 1-66 illustrates some of the vehicle characteristics examined in the study of quantitative cost estimates likely to be paid for various attributes. In addition to the vehicle cost/attribute questions related to Figure 1-6 the initial market survey also tested for demographic information as a cross-check on the socio-behavioral demographic data and consumer characteristics. A complete set of marketing survey questionnaires are contained in Appendice C and D. Based upon the marketing/economic results obtained from the vehicle attribute study a second phase of surveys were conducted to determine the estimate of market penetration under various fuel/energy supply scenarios. Five basic scenarios were examined in this phase of the market demand penetration study. Scenarios included considerations such as:

1.) Future gasoline and alternate energy prices remain relatively constant with current costs;
2.) Future gasoline prices continue to drop at a rate similar to that shown in Figure 1-3 for the years 1981 through 1985 such that gasoline costs become the same or less than alternate energy;
3.) Future gasoline prices rise and alternate energy sources such as natural gas become much cheaper than gasoline;
4.) Fuel/energy prices remain as in scenario 1, but state government incentives are allowed for alternate energy vehicle systems; and
5.) A petroleum energy crisis occurs which drastically raises the price of gasoline but AE vehicle conversions are also very costly.

Figure 1-7 illustrates the relationship of scenarios to vehicle types and costs, tested in the demand penetration study phase of this research project. Figures 1-8, 1-9, and 1-10 present, respectively, a brief summary of the consumer demand approach, the vehicle choices presented to the respondents, and a summary of the demand results.

The forecasts of fuel use and ADOT revenues under alternate energy penetrating scenarios required that the <u>demand survey</u> data be integrated with the ASU ADTFUEL model [11] to generate:

1. Vehicle miles traveled by vehicle type;
2. Use tax revenues by vehicle type;
3. Total vehicle purchases per year by type; and
4. License tax revenues by vehicle type.

The demand survey data provides the basis for estimates of taxpayer response to any tax change since any tax/license fee will change either the purchase price or operating cost of a vehicle. Details of the demand survey and market penetration studies are presented in sections 5 through 6 of this report.

The results of the demand penetration survey study indicated that the compressed natural gas (CNG) vehicle was the most likely AE system to penetrate the Arizona transportation vehicle market in the next 5 to 15 years. As a result of the above the NAU Forecast Model (termed NAUFC) was developed by taking into account the most likely AEV system and associated costs.

The NAU Forecast Model predicts the penetration of CNG technology vehicles into the private fleet of Arizona. Regular demand studies should be made to ascertain if there is any change in the type of AE system likely to penetrate the Arizona market. Any changes with associated costs, etc., can be easily input to the NAU Forecast Model by a change of variables and certain parameters discussed in detail in section 6 of this report. Figure 1-11 illustrates the general input provided to the NAU Forecast Model. The NAU Forecast (F6) Model is written in two versions, Fortran and Pascal. The NAU-FC Model can be run on either a micro-computer such as a Vax, or a larger main frame such as the Honeywell DPS-8. A desk-top personal computer version is also available but does not have the accuracy capability of the larger machine versions of the program.

The NAU-FC Model allows user inputs such as: 1) duration (years) of simulation desired; 2) specific downstream year for introduction of AEV technology; 3) future hypothesized values for the prices of gasoline and AE fuel; and 4) fuel tax rates. The NAU-FC Model output provides, for various scenarios, information on: AEV penetration; miles traveled; and amount of gasoline used. Thus, the user inputs can be used by the modeler to test the sensitivity of the system output, such as gallons of gasoline reduction, to factors such as sales tax incentives on AE vehicles versus higher taxes on the gasoline vehicles thereby stimulating a certain amount of penetration toward the AEV's. As shown by Figure 1-11 the model was constructed using data from several sources.

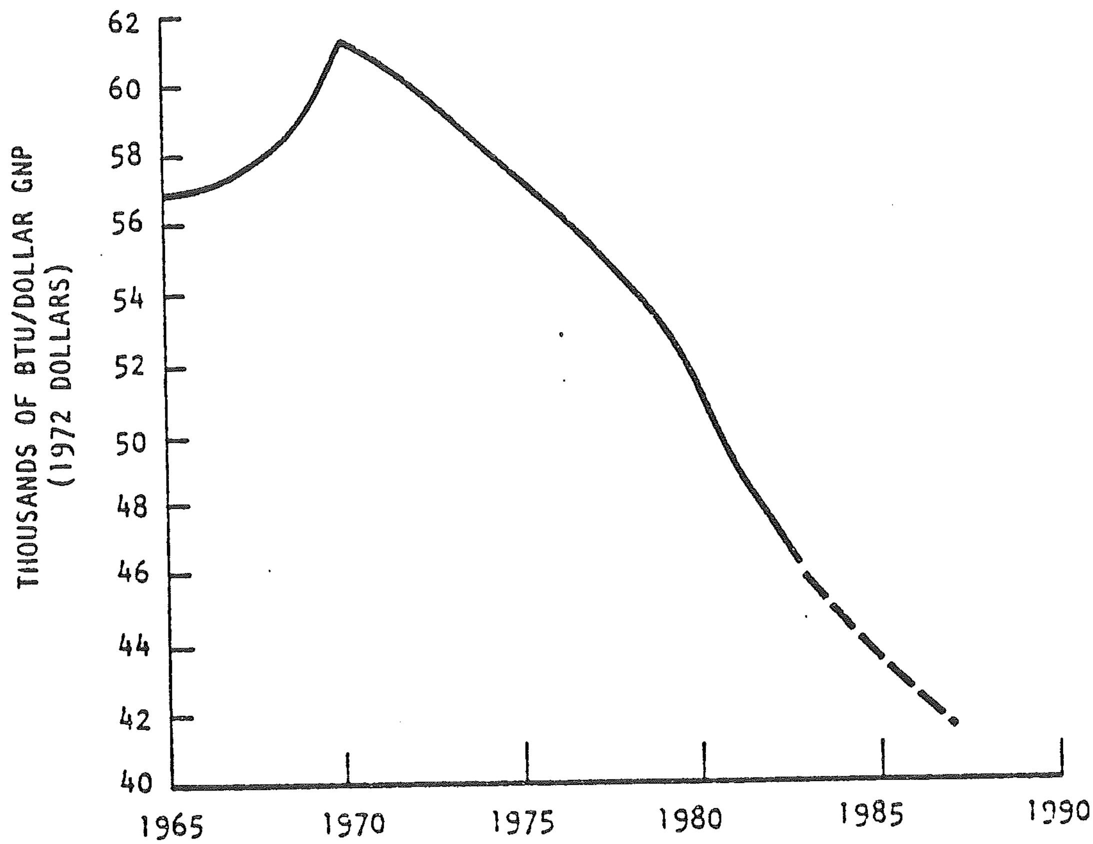
The data for Arizona fleet size and miles traveled in Arizona are from the Arizona State University (ASU) multi-linear regression models developed for ADOT in 1981 under grant number N-800-266 [11]. The data for innovation and penetration levels are from the NAU behavioral, technological, and market studies. Due to the fact that the ASU model assumed incorrectly in 1981 that the price of fuel was going to continue rising (see Figure 1-3) it was necessary for the NAU research team to request updated registration data from ADOT for the years from 1982 to 1985. Figure 1-12 illustrates a list of the data requested from ADOT. Some of the data was provided from the ADOT to the NAU research team; in many instances however it was necessary for the NAU research team to use national average data and adjust for the Arizona population in order to correct the ASU data base used in the NAU-FC model. It is strongly suggested that the ADOT maintain a yearly update of the NAU information gathered thus far to keep the ASU input current and as accurate as possible.

Although great effort was taken in this study to provide accurate quantitative data, several assumptions were also required and went into the model. Thus the output of the model is only as good as the uncertainty of the future scenarios, energy prices, and conversion/manufactured vehicle costs. In general the NAU-FC model results indicate that the model is good enough to predict general trends, but not exact quantities. As noted, details of the forecast model along with illustrative examples are contained in section 6 of this report. In addition, a Volume II: User Manual for the NAU-Forecast Model has also been generated which details the operation of the code.

Figure 1-13 illustrates the major phases, amount of funding, and time schedule used in the 2 year NAU study. It should be noted that although the NAU/ADOT contract was actually executed in late 1983, the teaching schedules of the NAU faculty had been established through May of 1984 and hence the contract work did not get underway until the summer of 1984.

FIGURE 1.1

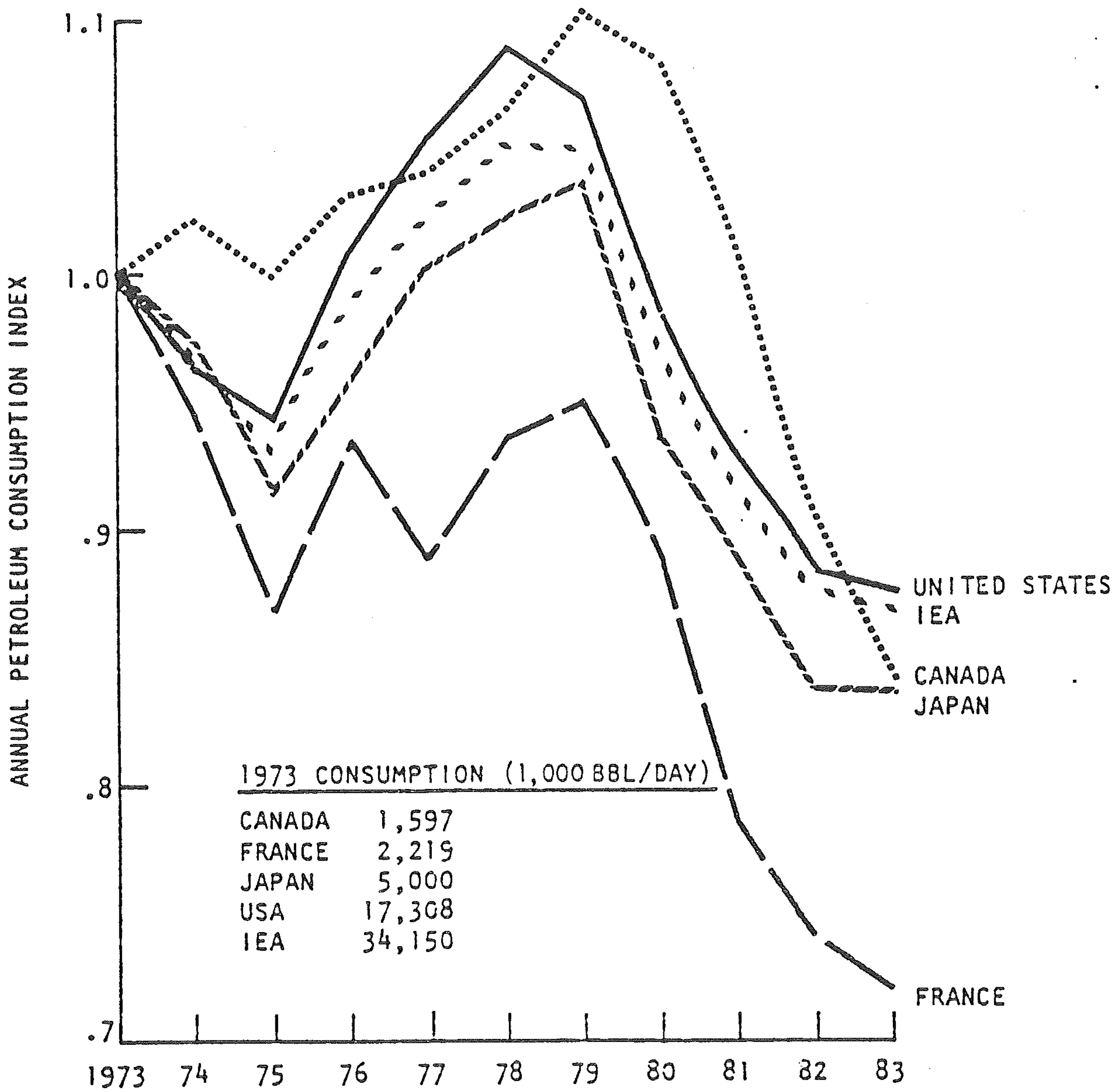
U.S. PRIMARY ENERGY CONSUMPTION
PER UNIT OF GNP



SOURCE: DOE/EIA, MONTHLY ENERGY REVIEW, MARCH 1984.

FIGURE 1.2

CHANGES IN PETROLEUM CONSUMPTION
SINCE 1973 FOR
SELECTED INDUSTRIALIZED COUNTRIES



SOURCE: DOE/EIA MONTHLY ENERGY REVIEW, APRIL 1984.

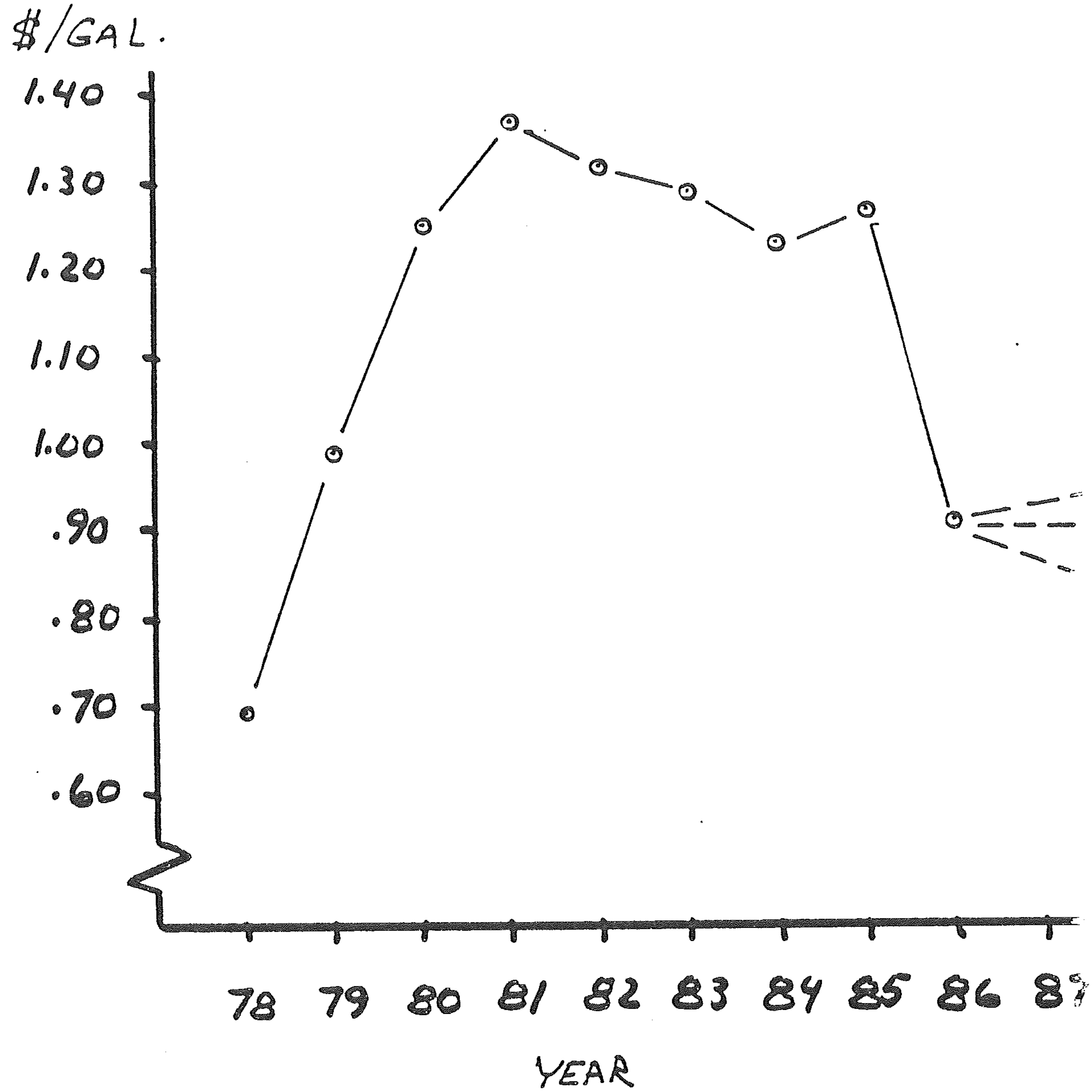


FIG. 1.3 GASOLINE COSTS (U.S

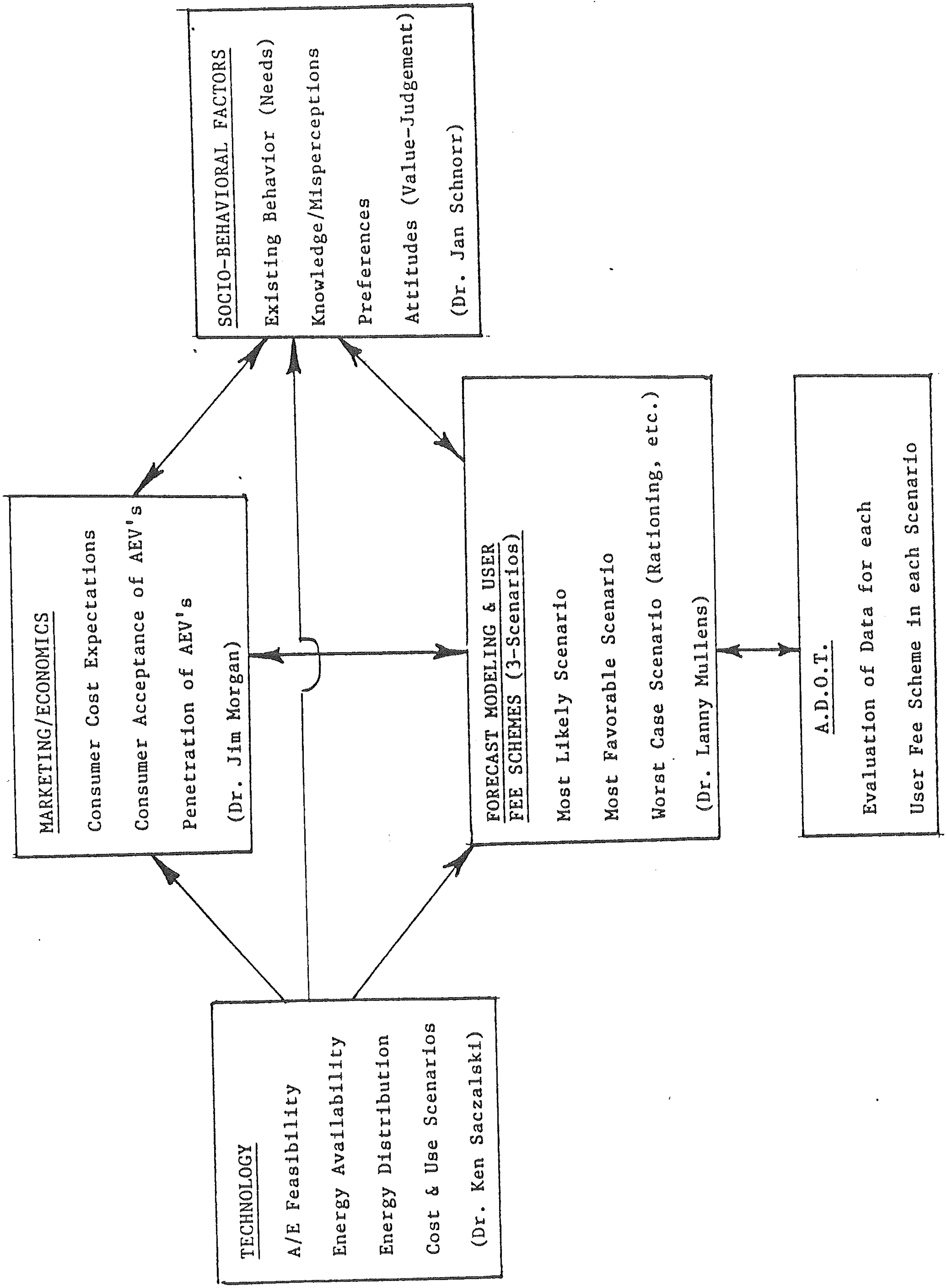

SOCIO-BEHAVIORAL FACTORS
Existing Behavior (Needs)
Knowledge/Misperceptions
Preferences
Attitudes (Value-Judgement)
(Dr. Jan Schnorr)
MARKETING/ECONOMICS
Consumer Cost Expectations
Consumer Acceptance of AEV's
Penetration of AEV's
(Dr. Jim Morgan)
FORECAST MODELING & USER FEE SCHEMES (3-Scenarios)
Most Likely Scenario
Most Favorable Scenario
Worst Case Scenario (Rationing, etc.)
(Dr. Lanny Mullens)
A.D.O.T.
Evaluation of Data for each
User Fee Scheme in each Scenario
TECHNOLOGY
A/E Feasibility
Energy Availability
Energy Distribution
Cost & Use Scenarios
(Dr. Ken Saczalski)

FIGURE 1.4

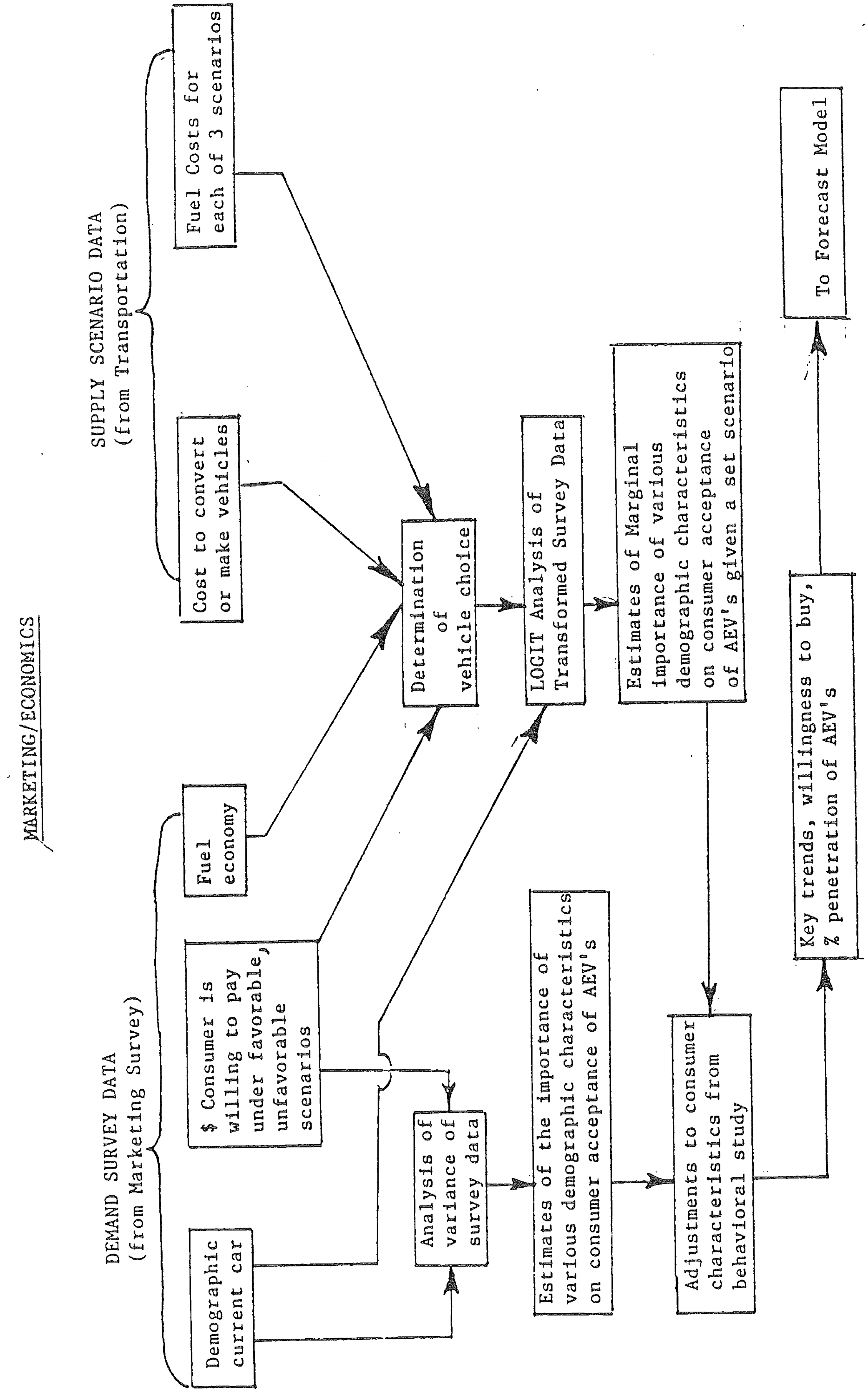

MARKETING/ECONOMICS
DEMAND SURVEY DATA
(from Marketing Survey)
SUPPLY SCENARIO DATA
(from Transportation)
Demographic
current car
$ Consumer is willing to pay under favorable, unfavorable scenarios
Fuel economy
Cost to convert or make vehicles
Fuel Costs for each of 3 scenarios
Analysis of variance of survey data
Determination of vehicle choice
LOGIT Analysis of Transformed Survey Data
Estimates of the importance of various demographic characteristics on consumer acceptance of AEV's
Estimates of Marginal importance of various demographic characteristics on consumer acceptance of AEV's given a set scenario
Adjustments to consumer characteristics from behavioral study
Key trends, willingness to buy, % penetration of AEV's
To Forecast Model

FIGURE 1.5

FIGURE 1.6

TENTATIVE LIST OF ATTRIBUTE LEVELS

Fuel Cost Per 10000 Miles of Travel		4 Levels
	$ 250	
	$ 500	
	$ 750	
	$1000	
Range Before Refueling		3-4 Levels
	50 miles	
	100 miles	
	150 miles	
	300 miles	
Passenger Capacity		2 Levels
	2	
	4	
Trunk Capacity		2 Levels
	1/2 that of Typical Current Compacts	
	Identical to Typical Current Compacts	
Type of Fuel/Refueling Time		3-4 Levels
	Gasoline/Quick Fill	
	Electric/Overnight	
	CNG-LNG/Quick Fill & Overnight	
	Hydrogen/Quick Fill & Overnight	
	Total Attribute Combinations	144 to 256

FIGURE 1.7

SUPPLY SCENARIO SPECIFICATIONS

	SCENARIO				
	1	2	3	4	5
Purchase Price AV-Conventional Vehicle:					
Car 1 (Natural Gas)	$ 800	$1800	$ 800	$ 800	$ 1800
Car 1A (Natural Gas with with home refueling)	$1500	$2500	$1500	$1500	$ 2500
Car 2 (Hybrid-Retrofit)	$2200	$2200	$2200	$2200	$ 3200
Car 2A (Hybrid-Mfg.)	$1700	$2700	$1700	$1700	$2700
Fuel Cost Per Mile					
Natural Gas - Gasoline	- 1	- 5	- 3	- 1	-3
Other Scenario Features:					
Sales Tax Exemption for AVs	No	No	No	Yes	No
Rationing	No	No	No	No	Yes

CONSUMER DEMAND SURVEY APPROACH

ADMINISTER SURVEY AS PART OF A PRESENTATION DESCRIBING AV TECHNOLOGIES

SURVEY SERVICE ORGANIZATIONS, COMMUNITY COLLEGE/UNIVERSITY CLASSES (ATTEMPT TO SURVEY GROUPS AS REPRESENTATIVE AS POSSIBLE OF THE GENERAL POPULATION)

USE DEMOGRAPHIC DATA GATHERED WITH SURVEYS TO ADJUST SURVEY RESULTS TO REPRESENT THE POPULATION

FIGURE 1.8

VEHICLE CHOICES PRESENTED:

TYPICAL CURRENT VEHICLE

TYPICAL CURRENT VEHICLE IMPROVED MILEAGE

VEHICLE WITH 200 MILE RANGE 12 MINUTE REFUELING (CNG/HYDROGEN)

AS ABOVE WITH OVERNIGHT HOME REFUELING TO A 75 MILE RANGE (CNG)

HYBRID VEHICLE - GASOLINE OPTION 350 MILE RANGE 6 MINUTE REFUELING PLUS ALTERNATE SOURCE OVERNIGHT REFUELING FOR A 75 MILE RANGE (GASOLINE - CNG/GASOLINE - ELECTRIC)

AS ABOVE WITH HALF OF TRUNK SPACE USED BY ALTERNATE FUEL TANK (GASOLINE - CNG RETROFIT)

VEHICLE WITH 50 MILE RANGE AND OVERNIGHT REFUELING (ELECTRIC)

AS ABOVE WITH 100 MILE RANGE (ELECTRIC)

AS ABOVE WITH 350 MILE RANGE (ELECTRIC)

FIGURE 1.9

PRELIMINARY RESULTS

SIGNIFICANT NUMBER OF RESPONDENTS WOULD CONSIDER SWITCHING TO CNG VEHICLES AT CURRENT OR MARGINALLY IMPROVED PRICES

SHORT RANGE LONG REFUELING TIME OF ELECTRIC VEHICLES MAKE THEM AN UNATTRACTIVE ALTERNATIVE FOR MOST CONSUMERS

UNDER RATIONING OPERATING COSTS BECOME LESS IMPORTANT

TECHNOLOGIES TREATED

- CNG
- HYDROGEN
- ELECTRIC
- CNG - GASOLINE
- ELECTRIC - GASOLINE

FIGURE [illegible].10

SIMULATION - FORECAST MODELING

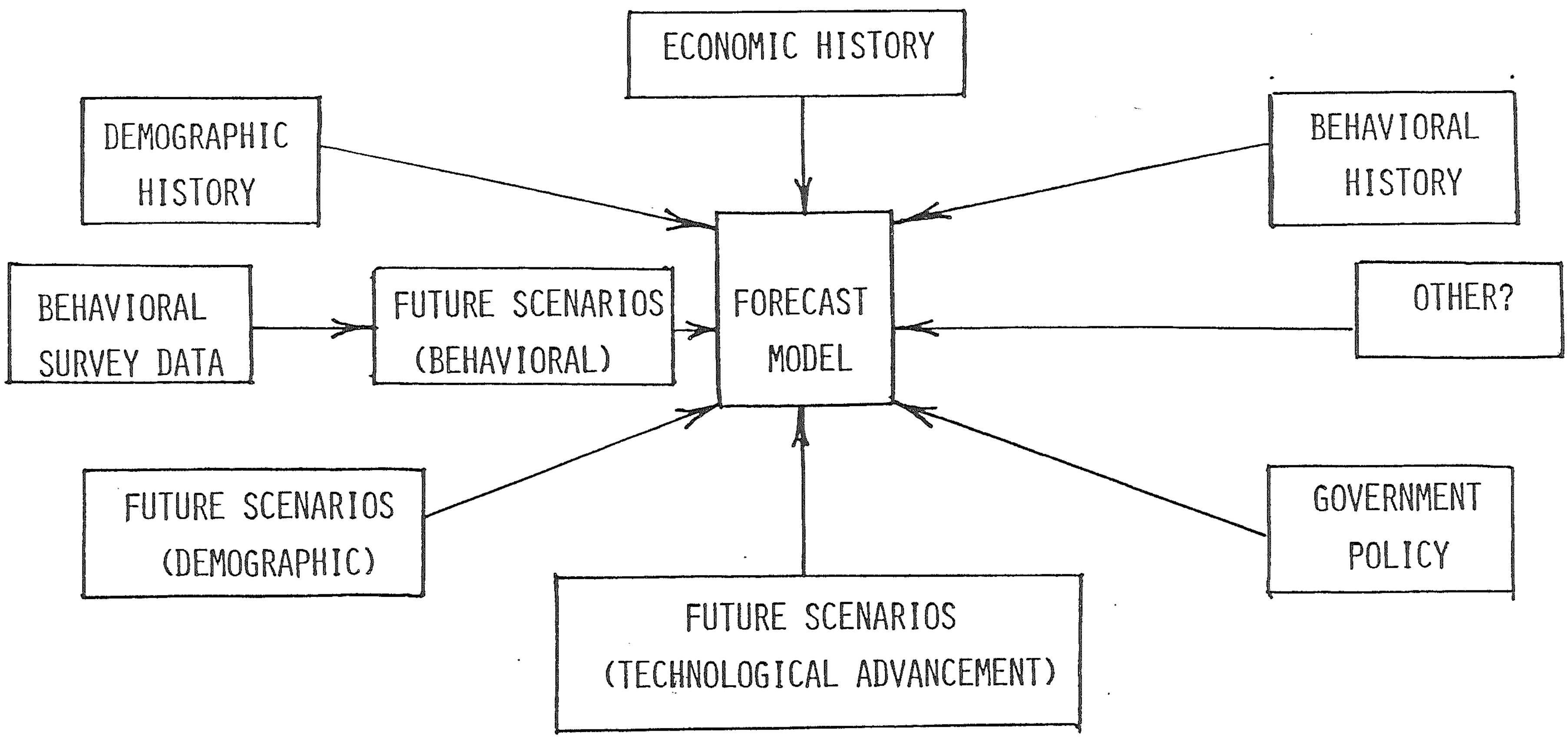


FIGURE 1.11

ARIZONA VEHICLE REGISTRATION DATA REQUESTED FOR NAU ADOT SPONSORED RESEARCH PROGRAM (83-86)

(For Years 1968, 1973, 1978, 1983)

1. Number of Licensed Drivers in Arizona

    A. Number of Males and Females
    B. Number of Drivers Below 20 years of age.
    C. Number of Drivers 20 to 34 years of age.
    D. Number of Drivers 65 years of age and above.

2. List or number of registrations for alternate energy vehicles by type (i.e., Electric, Propane, Natural Gas, etc.) and whether commercial or private.

3. Number of private registrations vs. commercial registrations.

4. Total number of registrations for cars, buses and trucks.

5. Average number of vehicles per household, if possible.

6. Average miles per vehicle per year.

7. Average amount of fuel used per year by each vehicle type.

FIGURE 1.12

MAJOR PHASES OF A/E STUDY & TIME SCHEDULE

	SUMMER 1984	FALL 1984	SPRING 1985	SUMMER 1985	FALL 1985	SPRING 1986	SUMMER 1986
1. TECHNOLOGICAL FEASIBILITY OF ALTERNATE ENERGY	X	X	X				
2. A/E FUEL DISTRIBUTION INFRA-STRUCTURES	X	X	X				
3. ENERGY AVAILABILITY, COST & USE SCENARIOS	X	X	X				
4. BEHAVIORAL ATTITUDES, ECONOMICS MARKETING	X	X	X	X	X		
5. FORECAST MODELING, USER FEE SCHEMES, & CODE DEVELOPMENT			X	X	X	X	
6. USER MEETINGS, SEMINARS & WORKSHOPS ON USE OF CODE					X	X	X

TOTAL FUNDS AVAILABLE FOR PROJECT - $ 88,500.00

FIGURE 1

SECTION 2

AE TECHNOLOGICAL FEASIBILITY

2.1 ENERGY AVAILABILITY: SOME POSSIBLE FUTURE SCENARIOS

In his interim report on "Alternate Energy - Issues and Perspectives" [12], Dr. William M. Brown of the Hudson Institute notes several world events which have obvious implications on the availability of U.S. petroleum supplies and the subsequent levels of petroleum prices to U.S. consumers. Figure 2.1 shown below lists some of the potential energy related events cited in reference 12.

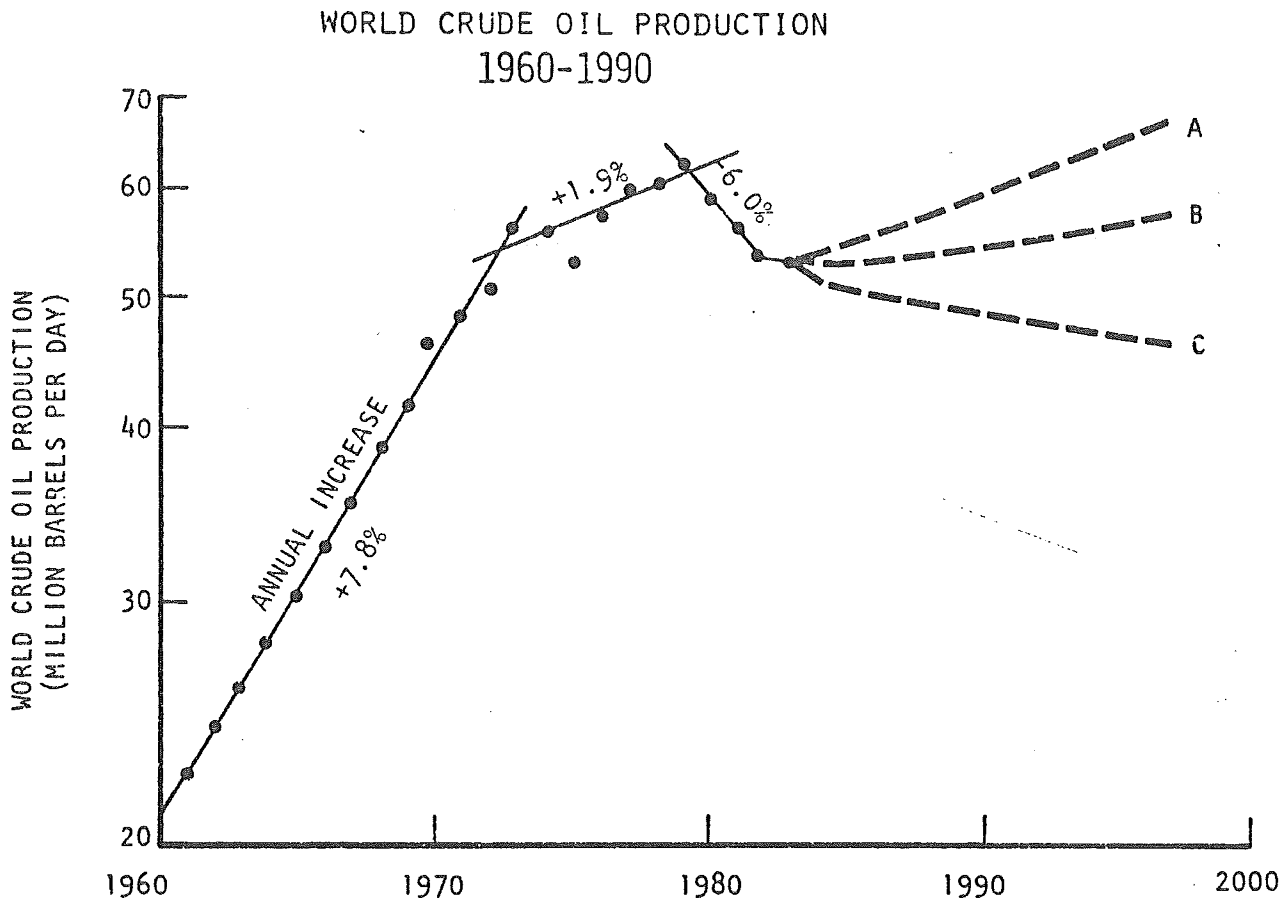
1. Energy Conservation and Energy Efficient Designs
2. Saudi Arabian Pricing and Production Incentives
3. Deregulation of Natural Gas Prices
4. Energy Taxes in Import-dependent Nations
5. Energy Production Incentives for Conventional and Unconventional Energy Sources
6. Mexican Oil and Gas Production
7. Soviet Oil and Gas Exports
8. Outcome of the Iran-Iraq War
9. Soviet Incursion into Iran

Figure 2.1 Possible Energy Related Events Which Would Impact Fuel Prices

As noted in section 1.1 and shown in figure 1.2 the U.S. and other selected industrialized nations have adopted rather successful energy conservation measures since the first energy crisis of the early 1970 time frame. The impact of these conservation measures has resulted in drastic reductions in energy consumption levels. In addition, the level of world crude oil production has started to decline due to a surplus in world petroleum supplies (related in large part to successful conservation measures) which resulted in lower demand and subsequently lower prices to certain petroleum producing nations such as Saudi Arabia. These trends of lower production levels and reduced costs in terms of U.S. dollars paid per barrel of crude oil are shown in figures 2.2 and 2.3, respectively. The result of these conservation and production measures as related to the price of gasoline paid at the pump by U.S. consumers was dramatically illustrated by figure 1.3 which shows a drop of about 34% in consumer gasoline costs from 1981 to 1986.

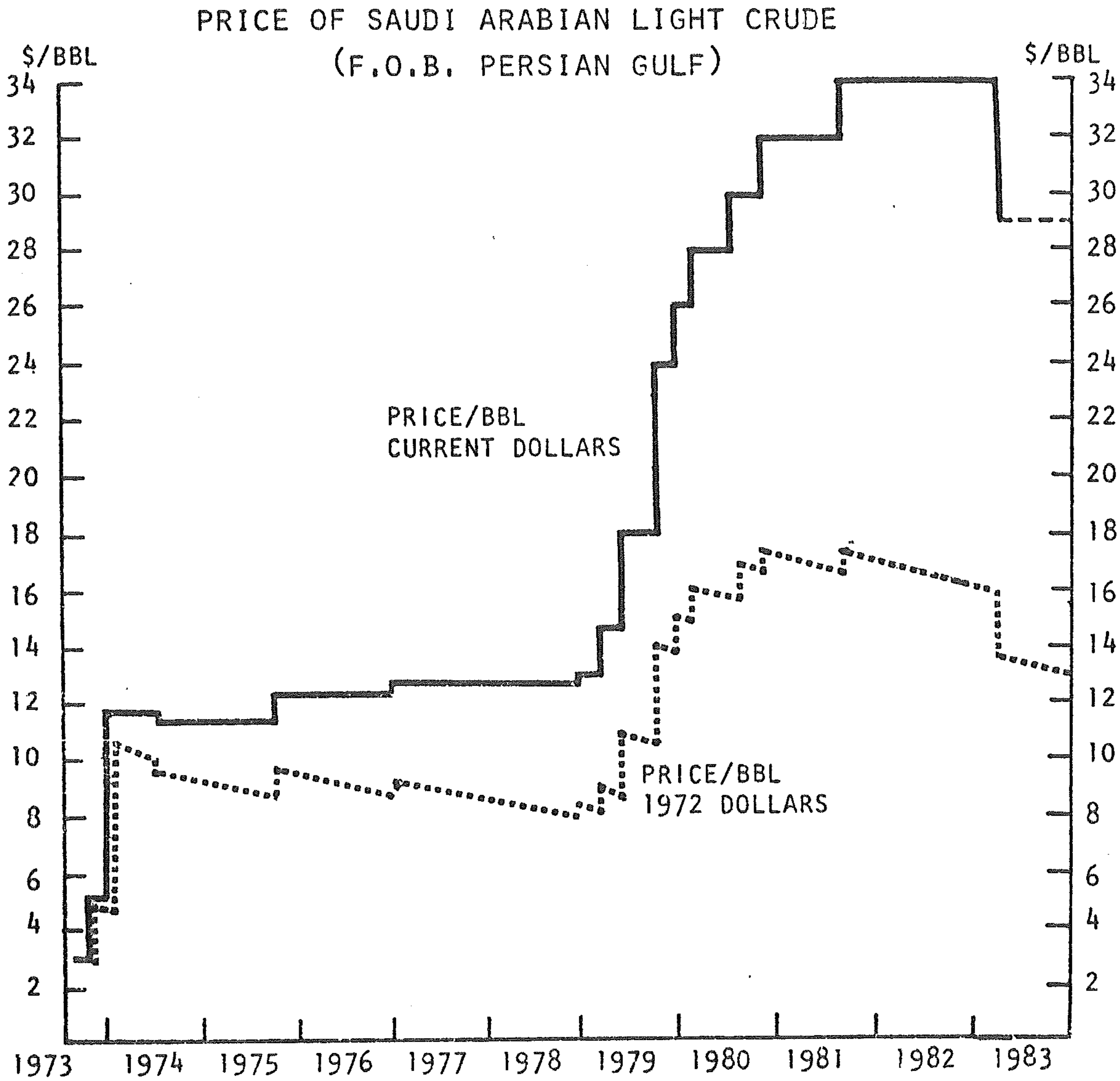
It is interesting to note that during the time period prior to 1981, and up to as recently as 1984, most forecasters associated with large institutions, such as CONOCO and TEXACO, were predicting a relatively stable world demand for oil with future growth of about one to two percent for the next 20 years [12]. In line with the demand predictions were similar predictions of a steady increase in gasoline prices for the U.S. consumer (in spite of the actual downward trend since 1981 exhibited in figure 1.3). Similar predictions were used in the ASU/ADOT Forecast Model [11]. Contrary to the above prediction, Dr. William M. Brown has suggested [12] that a more likely scenario for future energy prices, at least for the next five

FIGURE 2.2



SOURCE: DATA COMPILED FROM DEPARTMENT OF ENERGY PUBLICATIONS.

FIGURE 2.3



SOURCE: PETROLEUM ECONOMIST, AS COMPILED BY W.M. BROWN.

years (i.e. 1985 to 1990), would be the downward trend that is evident today in 1986. Furthermore, in 1980 and 1981 when all other forecasters were predicting a rise in the cost per barrel of crude oil (and noting the strength of OPEC), Dr's. William M. Brown and Herman Kahn predicted that OPEC's oil exports would shrink (which they did) and that oil prices would decline (which they did) [13, 14]. Furthermore, in his 1984 report to the NAU Alternate Energy Research Project Group, Brown [12] suggested that the price of crude oil would more than likely drop to less than $15.00 per barrel by 1985 (current 1986 prices are approximately $13.50 per barrel).

Obviously, in light of the above recommendations by Brown [12], one scenario implemented in this AE study included that of decreasing petroleum prices at the rate of about 3% per year, for at least the next decade, with a bottom out price of about 65 cents per gallon. As noted, the above scenario (termed scenario - 1 hereafter) was driven primarily by energy conservation and the pricing and production rates of certain OPEC members. Brown points out that higher energy taxes applied to petroleum products used in import-dependent nations would continue to encourage energy conservation measures and help maintain the more stable and somewhat lower fuel costs.

Another factor which has in the past played a significant role in increasing U.S. dependency on foreign oil imports was the U.S. federal government control on natural gas (NG) prices [12, 15]. As the NG prices were held artificially low and manipulated by the federal government there was less and less monetary incentive for U.S. and world energy producers to continue to produce natural gas. Figure 2.4 illustrates the well head price of natural gas in $ per thousand cubic feet for the years since the 1954 Supreme Court ruling (which allowed government regulation of NG) up to the 1980 time frame.

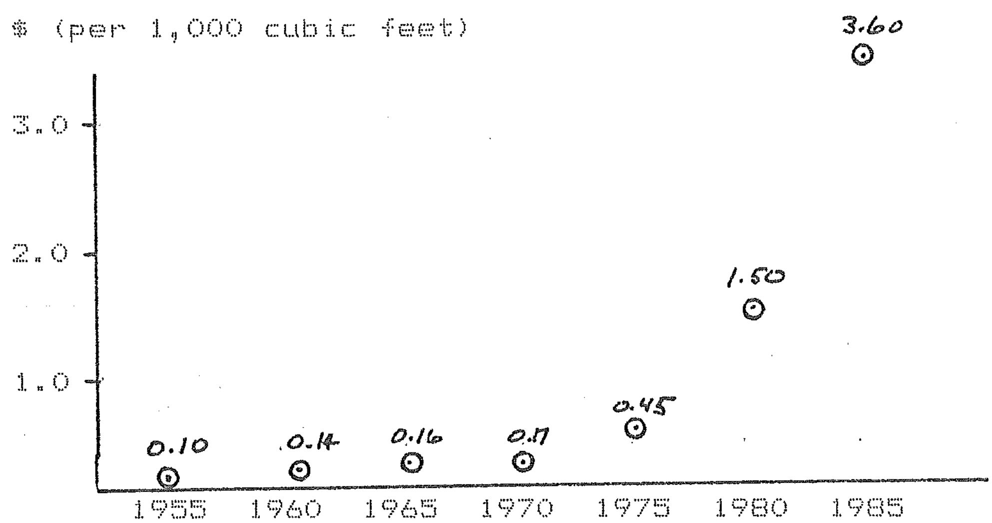


Figure 2.4 Average Gas Prices at the Well Head per 1,000 Cubic Feet
(Data Compiled by K. J. Saczalski)

One result of the U.S. government control on natural gas prices is the fairly low level of market production for both the U.S. and the world as illustrated by figure 2.5. Oppenheimer [15] notes that "from the well head to the point of end use, natural gas enjoys significant cost advantages over oil". Brown also feels that with deregulation the price of natural gas should rise enough to make it more attractive to produce NG but at the same time it will be cheaper than oil due to the tremendously lower production costs when compared to processing and shipping of crude oil.

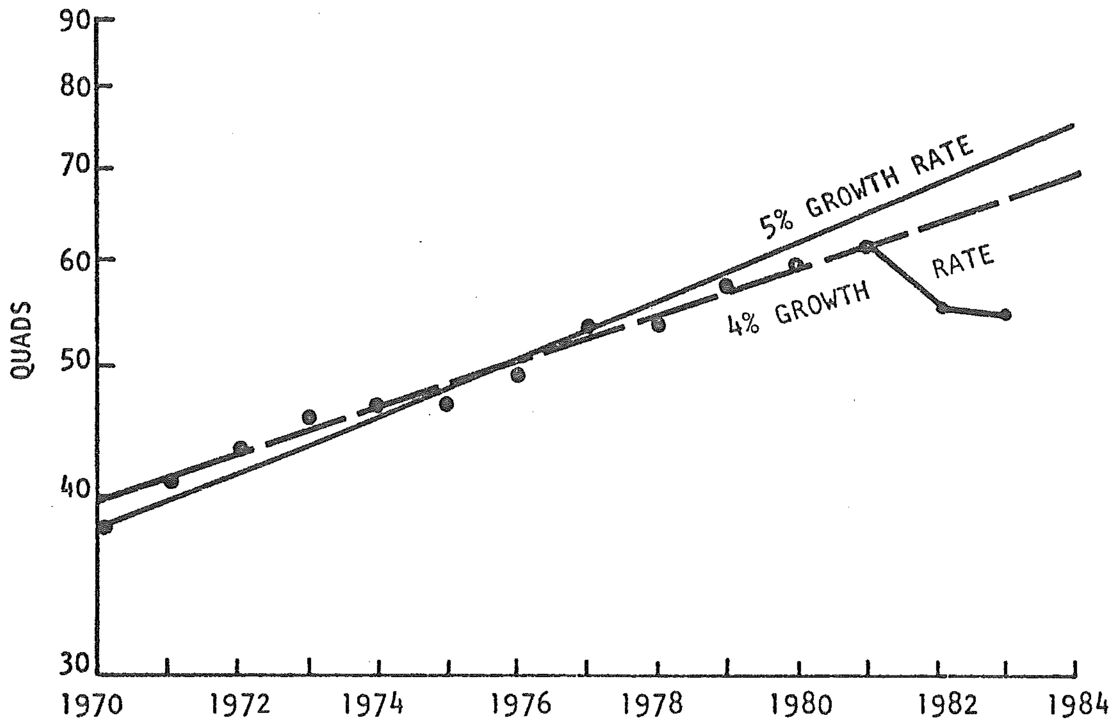
The Phoenix and Tucson areas have a very well laid out natural gas pipeline throughout the urban/metropolitan areas. Ease of access of NG for an AE transportation source, coupled with a relatively cheaper cost per mile and cleaner emissions, makes NG an attractive alternative to gasoline transportation systems in Arizona. Thus, the competition from deregulated NG is also likely to keep the cost of gasoline at lower levels.

Because of the large infra-structure of the oil industry, and the significant market, any potentially serious competitive threats of alternate energy are probably going to be met by decreased gasoline or petroleum costs until a bottom level of about 65 to 70 cents per gallon is reached. Several other factors can also effect the availability and cost of petroleum. Some of these factors include increased oil and gas production in Mexico, the Soviet Union, and other oil exporting countries which would tend to also keep the price of gasoline low over the next several years. Brown feels that the economic problems currently faced by Mexico will, for various obvious reasons (i.e. bad credit and no international loans for increased oil exploration and production), only maintain current oil production levels at best (see figure 2.6) [12].

An important factor which could result in a return to <u>increased petroleum costs</u> deals with the development of a crisis situation. Obviously we cannot predict with any certainty when

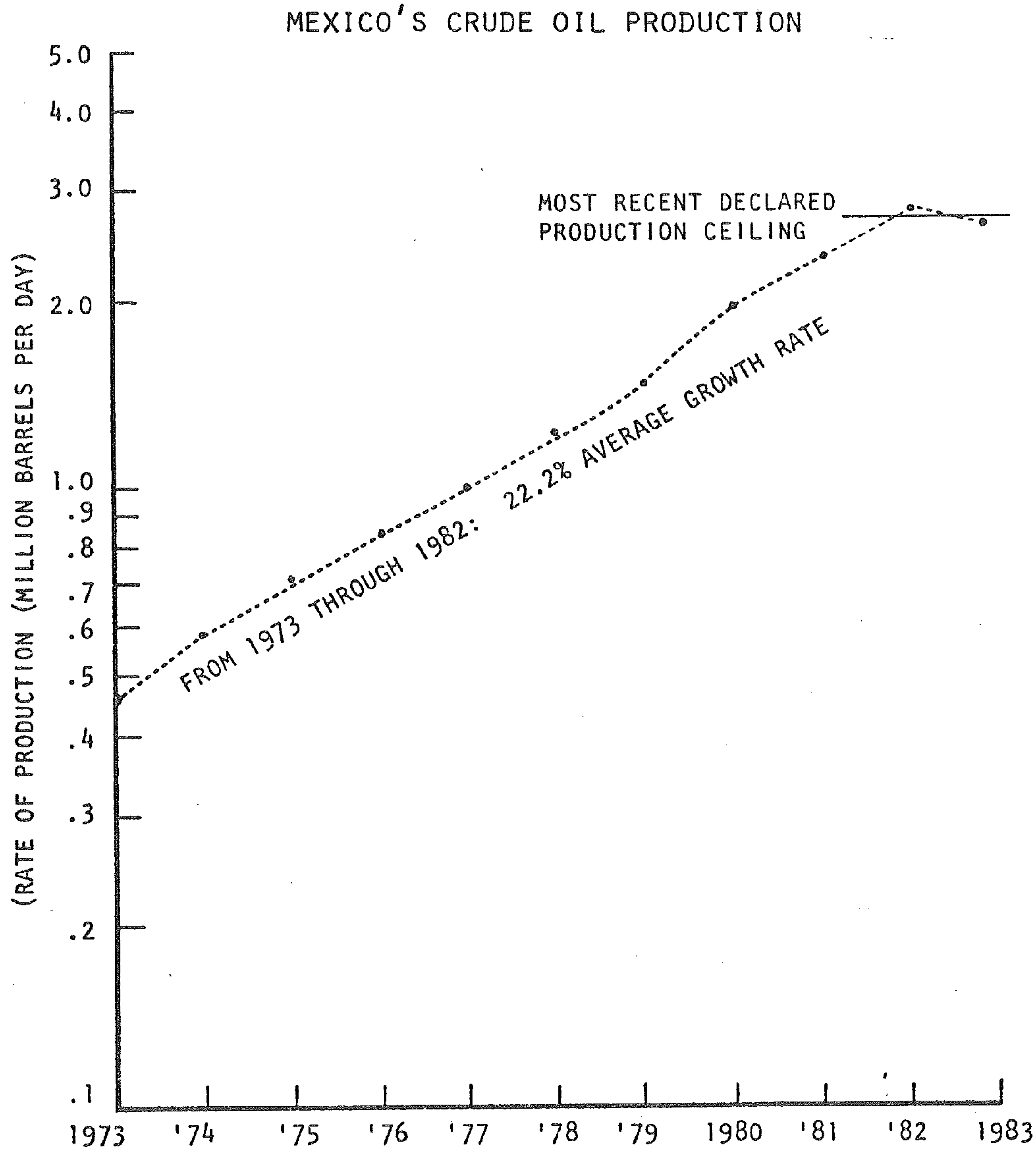
FIGURE 2.5

MARKETED PRODUCTION OF NATURAL GAS - WORLDWIDE



DATA SOURCES: BASIC PETROLEUM DATA BOOK, OIL & GAS JOURNAL.

FIGURE 2.6



SOURCE: DEPARTMENT OF ENERGY, ENERGY INFORMATION ADMINISTRATION DATA and if a crisis event is likely to happen; however, it is remotely possible that the IRAN-IRAQ situation could lead to a restriction on the availability of oil imports to the United States and other oil import dependent countries. Brown [12] explores several possibilities of outcome of the IRAN-IRAQ war which might lead to increases in oil prices. One possibility is that IRAN can take control of IRAQ, and eventually the other countries in the Persian Gulf region, ultimately reducing oil production and thereby increasing petroleum costs to almost any level they prefer, such as 40 to 50 dollars per barrel, for at least the next decade. Other negative factors could also trigger a crisis situation and increased consumer gasoline prices. For instance, while not likely, an incursion by the Soviet Union into IRAN (ala-Afghanistan) could also lead to unfriendly control over the Persian Gulf.

Thus, in addition to the decreasing gasoline cost scenario-1, the NAU Research Team also included a crisis situation scenario which included rationing of gasoline, increased gasoline costs, and increased costs of trying to convert to a dual fuel/AE system (due to anticipated high demand and low supply of AE conversion kits, etc.).

A third scenario which is quite feasible, and in fact is almost necessary if there is to be any significant influx of AEV's into the Arizona market, deals with the use of federal and/or state incentives to convert to AEV's such as CNG powered vehicles. Discussions held with gas industry [16] and automotive industry representatives [17] indicates that unless a significant market for AEV's is available (say 20,000 units per year) there will not be any mass-produced and dedicated AEV systems but more than likely only dual fuel conversions on conventional I.C. engine vehicles. Through the use of incentives, such as the sales tax reduction concept used in Canada for buyers of NG powered vehicles or vehicles converted to run on both NG and gasoline, the state of Arizona can encourage greater use of cleaner, less polluting, alternate energy systems. Ultimately (after sufficient time for turn-over of new vehicles and AEV's in the Arizona fleet) the incentives could provide for a large enough market to encourage the automotive industry to develop AE vehicles along with the necessary maintenance, repair and servicing infra-structure desired by the consumer.

The scenario 1 is the least favorable to market/demand penetration of AEV's into the state of Arizona. The third scenario discussed above (i.e. government incentives) is perhaps the most favorable to market/demand penetration of AEV's if one could assume that the price of gasoline was stable or at least increasing relative to the price of cheaper alternate energy sources.

In light of all of the above, and due to the uncertainty of the future, the NAU Alternate Energy Project Research Team selected five alternatives for examination in this study:

a.) Scenario-1 assumes that the relative prices of gasoline and cheaper alternate energy fuels, such as CNG, remain relatively constant over time. In addition it is assumed that AEV's are configured and priced competitively with the standard gasoline powered vehicles;

b.) Scenario-2 assumes the cost of gasoline to drop over the next decade and the cost of converting a vehicle to operate in a dual fuel (AE and gasoline) mode to be about $1500. Furthermore, this scenario assumes that there is only a minimal savings by using an alternate fuel source such as NG;

c.) Scenario-3 assumes that the cost of gasoline increases and that the difference in fuel costs afforded by using an AE system is about a 40% savings versus gasoline costs. The cost of purchase of an AE vehicle is assumed to be as in scenario-1;

d.) Scenario-4 is like scenario-1 with respect to fuel and vehicle costs except in this scenario various AEV adoption incentives are allowed; and

e.) Scenario-5 represents the crisis situation discussed previously where gasoline rationing is considered along with higher cost of gasoline and attractively lower AE costs.

2.2 ALTERNATE ENERGY TRANSPORTATION SYSTEMS

The national and world needs for transportation account for about 20% of all present energy use [18]. Currently, petroleum is the primary fuel/energy source for gas turbines, jet engines and internal combustion engines (ICE), such as the standard gasoline powered spark ignition (SI) type engines and the diesel fuel powered compression ignition (CI) engines. Concern with the environment, and the cost and availability of future petroleum supplies, has encouraged the research and development of numerous AE systems and energy sources or fuel modifiers. Table 2.2.1 lists the AE systems or energy/fuel sources researched in this phase of the study.

DIESEL FUEL
LIQUIFIED PETROLEUM GAS (LPG-PROPANE)
GASOHOL (10% ALCOHOL/90% GASOLINE MIX)
ETHANOL (FROM FERMENTATION)
METHANOL (FROM COAL & BIOMASS)
METHANE/NATURAL GAS (COMPRESSED-CNG & LIQUIFIED-LNG)
HYBRID DUAL FUEL SYSTEMS (GASOLINE & CNG or LPG)
ELECTRIC (BATTERIES)/HYBRID ELECTRIC
FLYWHEELS AND MECHANICAL ENERGY STORAGE DEVICES
HYDROGEN POWERED SYSTEMS
SOLAR AND FUEL CELL POWER

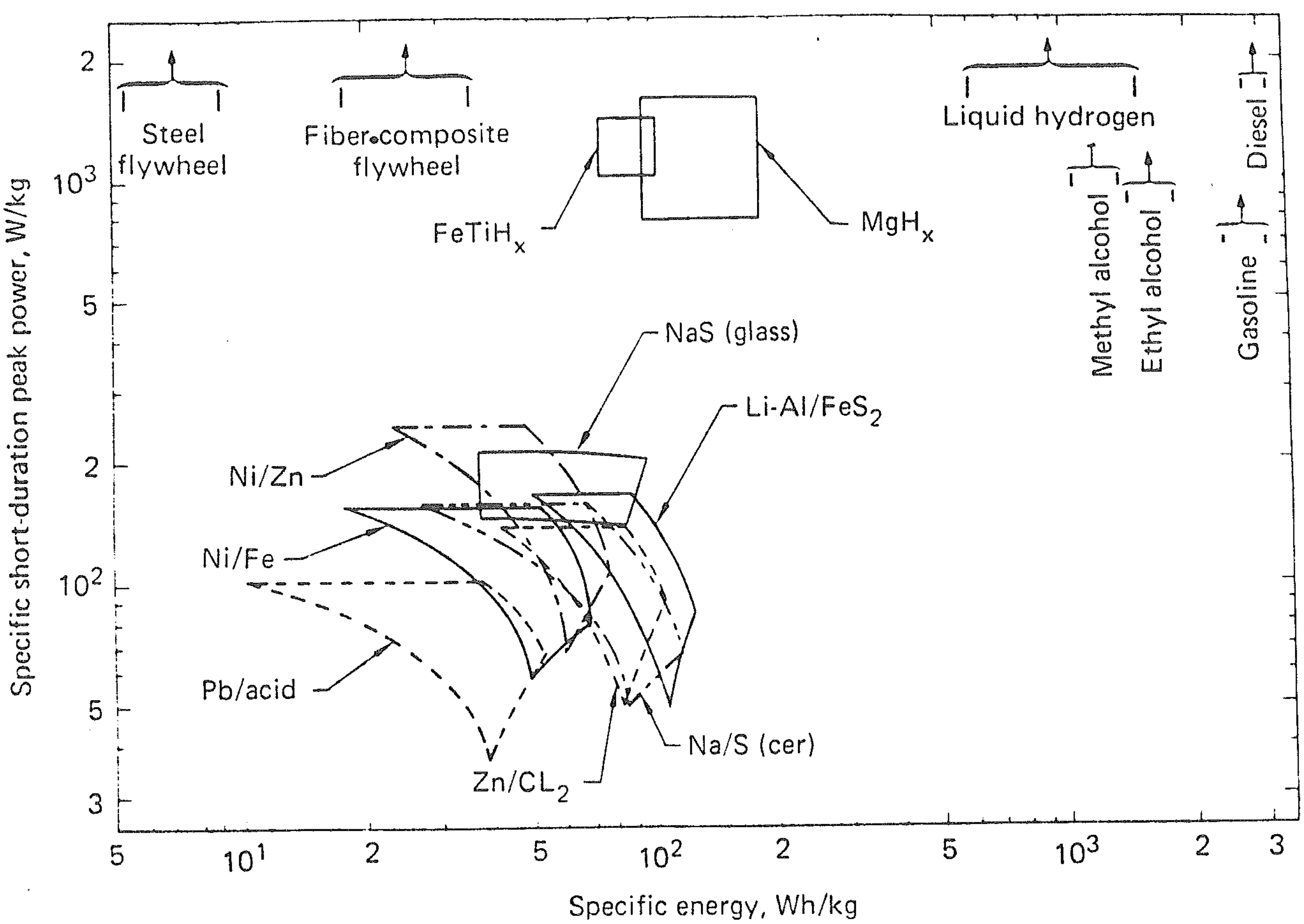
TABLE 2.2.1 SOME ALTERNATE ENERGY SYSTEMS AND POTENTIAL ENERGY SOURCES FOR TRANSPORTATION

2.2.1 ELECTRIC AND HYBRID/ELECTRIC: A DARK-HORSE AE SYSTEM FOR ARIZONA

Studies conducted by Arthur D. Little, Inc. [9] and ORI, Inc. [19] suggest that by the year 1990 the potential market for electric vehicles (EV) in warm and temperate climates of the U. S. will be about 2,700,000 vehicles. The warm climate and relatively flat terrains of the Phoenix and Tucson urban/metropolitan areas are features that would allow electric vehicles to operate at maximum performance. In addition, as noted previously, Arizona's abundant coal reserves, hydroelectric power, and nuclear power should eventually make electric power economically attractive if petroleum costs start to rise significantly. Finally, the electric power industry finds overnight charging of EV's a nice way to balance daytime/evening power demands and increase income without significant capital investment. The Arizona Public Service (APS) Utility Company has been successfully experimenting with a fleet of electric vehicles since the early 1980 time period [20].

Saczalski of the NAU College of Engineering & Technology has also examined the commercial feasibility of electric and hybrid electric vehicles for the colder winter climates and hilly regions of Flagstaff, Arizona [1]. An Electric Passenger Car Company hybrid/electric modified Ford Pinto station wagon was used in the NAU study. The results of the above study indicated that hybrid electric vehicles were technologically feasible and could compare reasonably well in energy costs to the ICE counterparts, however, battery maintenance and reliability of component parts, as well as replacement parts, and lack of servicing capabilities detracted from the commercial feasibility of such vehicles. The results of the study did indicate however that the above vehicles optimum use would be for trips under 30 miles in short commuter travel, downtown shopping, and errand running, in a relatively flat terrain and warm climate such as the valley areas of Phoenix and Tucson.

In virtually all current EV systems, however, lead/acid batteries are the source of energy. Figure 2.7 shows that the lead/acid batteries are poor in both energy density and specific peak power, as compared to most of the other AE systems illustrated [21]. Future battery systems (to be commercially available in the early 1990 time frame) such as the sodium sulfur (NaS) and the aluminum-air batteries [22] offer some improvement and potential for use as an Arizona AE system. The advantage of the aluminum-air battery is that it would allow a range of about 100 to 125 miles before requiring a refill of distilled water. About 3 to 4 water refills would be possible before the aluminum core would have to be turned in for reprocessing by the aluminum industry (i.e. like returning a glass bottle for deposit). Thus these batteries might be able to provide a range of about 350 to 500 miles to an electric vehicle, however, some mechanism of refuel or easy trade-in would have to be worked out before the improved batteries could become feasible. The Lawrence Livermore Laboratory [23] is actively working on the practical aspects of



Steel flywheel
Fiber composite flywheel
FeTiH$_x$
MgH$_x$
Liquid hydrogen
Methyl alcohol
Ethyl alcohol
Gasoline
Diesel
NaS (glass)
Li-Al/FeS$_2$
Ni/Zn
Ni/Fe
Pb/acid
Zn/CL$_2$
Na/S (cer)
Specific short-duration peak power, W/kg
Specific energy, Wh/kg

FIGURE 2.7

the problem and there is some optimism that the aluminum industry may be willing to assist in making the "trade-in" aluminum-air batteries a commercially feasible entity some time in the next few years. If such an improved battery system comes about in the near future, it is quite likely that the electric or hybrid/electric vehicles could become a potential candidate for penetration into the Arizona AE market. For instance, a consumer survey study conducted by Dan Shein at a Phoenix Electric Vehicle Mini-Fair in May of 1981 [24] found that while most consumers drove less than 50 miles per day, they expected a potential range of greater than 100 miles in any AE vehicle that they would consider purchasing. The aluminum-air battery system seems to satisfy at least the above consumer requirement.

2.2.2 FEASIBILITY OF ALTERNATE ENERGY TRANSPORTATION SYSTEMS

The complex manufacturing infra-structure associated with current automotive production, and the tremendous expense of developing new infra-structures for major deviations from current automotive propulsion systems, suggests that the AE systems most likely to replace gasoline in the next 10 to 20 years will be those systems which are amenable to internal combustion engine conversions or adaptability. The one possible exception to the above, cited in the previous section, is the electric and hybrid/electric vehicle with improved longer range batteries.

Two alternate fuels which have been used as popular substitutes to gasoline are the diesel and propane fuels.

Propane, a liquified petroleum gas (LPG), is a clean burning fuel which is produced as a result of processing crude oil at the refinery. To facilitate storage and transport, propane is liquified by a process of compressing and/or cooling. Approximately 270 gallons of vapor can be compressed into one gallon of liquid. Propane remains in a vapor state at atmospheric pressure and normal temperatures. When used as a motor fuel, propane is drawn into an internal combustion SI engine in a vapor state, and as such, mixes readily with intake air. Propane engine fuel is produced to an accepted specification (HD5) to assure uniform quality and smooth performance when used with the spark ignition type IC engine conversions.

Diesel fuel is also a derivative of crude oil processing.

Only 17% of a barrel of crude oil can be made into diesel fuel. Diesel fuel is used in compression ignition type internal combustion engines. As diesel fuel usage increases an excess of gasoline will become available resulting in possible lower costs of gasoline, but higher diesel fuel costs due to simple supply and demand.

The price of diesel fuel in the Flagstaff area is about one cent per gallon greater than unleaded gasoline. Similarly the price of LPG (propane) will also fluctuate and increase with the supply of gasoline and demand for propane. It should be pointed out, however, that a strong LPG market currently exists in the U.S. transportation sector. Arizona, on the other hand, seems to show a decline in the use of LPG for transportation purposes. Details on the U.S. and Arizona LPG and CNG markets and tax laws are contained in Section 4.

Thus, the prices of both diesel and LPG have risen with increased demand and both fuels currently cost slightly more than gasoline. In the State of Arizona, (Tucson and Phoenix), three major companies are responsible for most LPG conversions: 1) CAL-GAS, 2) Petrolane, and 3) DOXOL. Several smaller companies market conversion kits but do not offer installation. Approximately 750 conversions costing about $1,000, have been made since 1983 and this number reflects a substantial decline from the 1970's when gas supplies were more limited. Most conversions from motor gasoline to propane were by private companies and government owned fleet vehicles. <u>Some fleets that</u>

were converted during the 1970's have been reconverted back to conventional fuels because of the increased LPG costs. Because of the above processing and high fuel cost factors, as well as other factors such as emissions from diesels and safety/conversion costs for LPG, neither LPG or diesel fuels are considered as AE candidates likely to replace gasoline. Figure 2.8 illustrates the dramatic drop off in percent of new vehicle sales in the U.S. of diesel passenger cars and propane conversion up through 1983 [27].

Solar and fuel cell power which have been recommended as alternatives to gasoline powered transportation systems [25], are also not considered as feasible AE systems. Current solar devices are costly and inefficient (only about 16% of the absorbed energy from the sun in converted to AE use). Although some solar powered research vehicles have been built and tested in the U.S., Japan and Australia, none of these vehicles have been capable of providing the range, speed performance and size/comfort/safety features required for consumer marketing. Fuel cells offer some potential for improved energy efficiency and use in AE transportation systems, however, with the exception of a small amount of basic research being carried out at some universities and national laboratories there does not appear to be any serious industrial work being carried out on the commercial implementation, and development of infra-structure, of fuel cells for AE transportation systems.

Another AE approach which is not considered feasible in this study deals with the use of mechanical energy storage devices such as the composite flywheel and hydraulic accumulator. The reasons for not considering mechanical energy storage devices as feasible AE transportation substitutes for gasoline are apparent in Figure 2.9 which illustrates a comparison of the energy density (i.e. amount of energy stored in a unit of mass or weight of the system which produces the energy) for various future (1990) batteries, hydrogen energy systems (hydrides and liquid hydrogen), and mechanical energy storage devices [26]. The extremely low energy density of the mechanical type devices, coupled with their relatively high specific power capability (see Figure 2.7), suggests that these AE systems could most likely be used only as hybrids in conjunction with some other higher energy density source.

The most likely AE replacements for gasoline in the next 10 to 20 years appears to be: alcohol and alcohol extenders (i.e. "gasohol"); CNG dual fuel systems (i.e. vehicles which are capable of running on either gasoline or CNG); dedicated CNG powered vehicles; and hydrogen powered vehicles [26]. All of the above AE sources are capable of good performance on standard IC engines with relatively minor adaptations to the engine and fuel metering system. Also, each of the above AE sources has the capability of significantly reducing the level of most pollutants encountered in gasoline and diesel powered vehicles. With the exception of hydrogen, the alcohols and the CNG are actually cheaper or at least competitive pricewise with gasoline. The

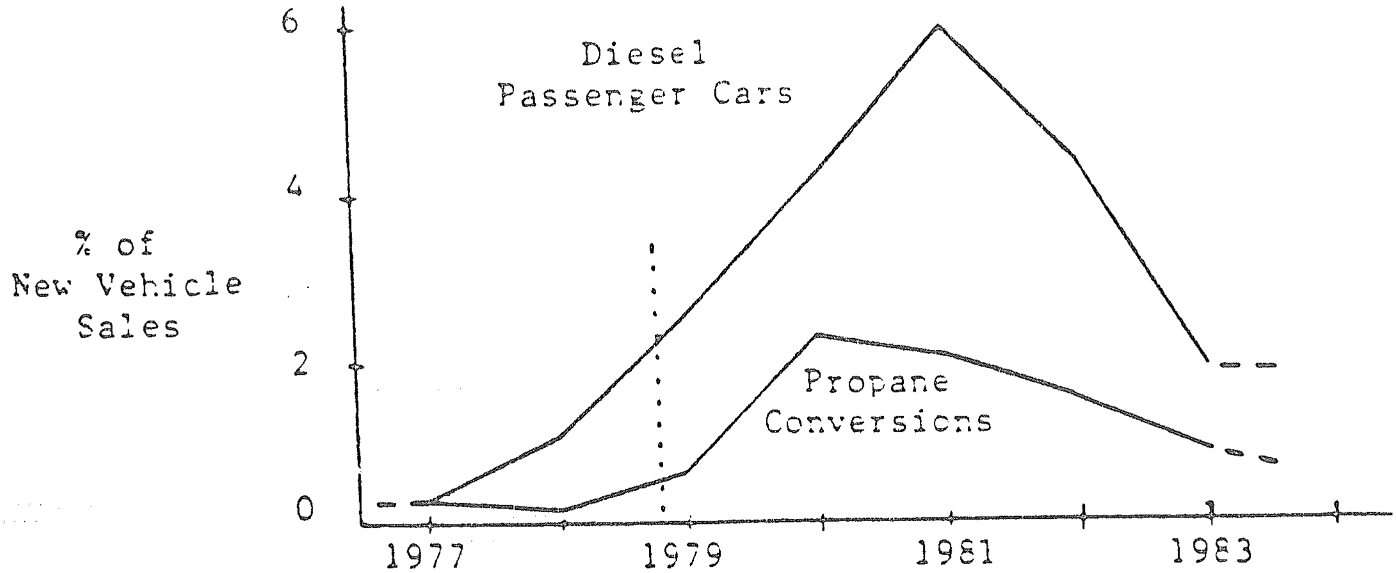


FIGURE 2.8

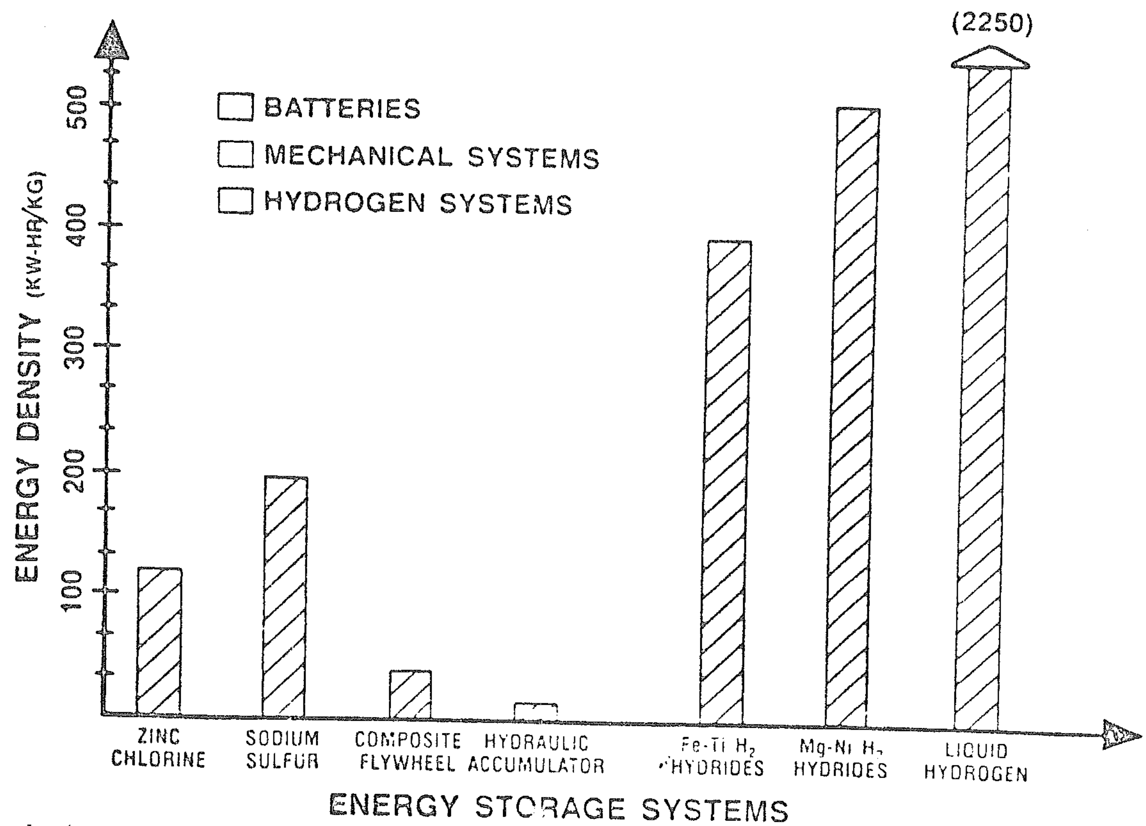


FIGURE 2.9

"gasohol' mix of 90% gasoline and 10% alcohol (ethanol) represents an immediate mechanism for "stretching" current U.S. reserves of gasoline. The biggest obstacle foreseen in the immediate conversion to blends of ethanol, even with only a 10% blend, is that more ethanol would be required than could be produced from available solid wastes and plant fermentation. As a non-lead octane enhancer "gasohol" sales have risen from 500 million gallons in 1980 to about 6 billion gallons currently.

Both ethanol and methanol have been used as the primary fuel source for automobiles. Methanol, currently derived from the abundant U.S. supply of natural gas, can be produced in large quantities. Methanol can also be produced from coal. Current 1985 best estimates put the amount of U.S. coal energy reserves at about 25 times the reserves of U.S. petroleum energy supplies [28]. The Ford Motor Company of the U.S. has initiated the development of methanol powered vehicles. The early problems encountered by "gasohol" corrosion of fuel system components have been alleviated by Ford through the use of appropriate non-corroding fuel system materials such as nickel plated parts [17]. Figure 2.10 outlines some of the unique features of the 1983 Ford Escort methanol system. A fleet of approximately 500 Ford methanol powered automobiles have been provided to the State of California, with another 100 vehicles (approximately) going to Canada, Pennsylvania and the City of Baltimore. A total of 33 fuel stations are provided in Southern and Northern California, and these stations are open to the general public [17]. The large U.S. supply of natural gas and coal suggests that methanol could be an excellent near term (5 to 15 years away) replacement to gasoline.

Germany and New Zealand have also considered using methanol as a substitute for gasoline. Ford has provided some vehicles to Germany which ran on 15% methanol and 85% gasoline. The U.S. difference in price between a conventional gasoline powered vehicle and a new methane powered vehicle is only about 5% (roughly $500 on a $10,000 vehicle). Ford is currently researching the possibility of an engine which can run on either gasoline or methanol [17]. Because of the gasoline/methanol differences in air/fuel ratios and timing, as well as cold start problems and flammability of methanol, the above cited dual fuel concept is a most challenging task.

Brazil, due to its large sugar cane growing capability, has since 1975 emphasized the use of ethanol (derived from fermentation and solid wastes) in vehicles to reduce its previous dependence of importing approximately 85% of its oil. The Ford Motor Company has since about 1979 provided a large number of ethanol powered passenger vehicles to Brazil. Ethanol uses the same fuel distribution system already in place for gasoline in Brazil. As of July of 1984 Brazil was importing only 48% of their oil needs - a dramatic reduction in imports of almost 45%. The Brazilian ethanol passenger car mix increased from 28.5% in 1980 to approximately 88% in 1983. As of 1984 there were 1,200,000 ethanol vehicles in Brazil. Some work has also been

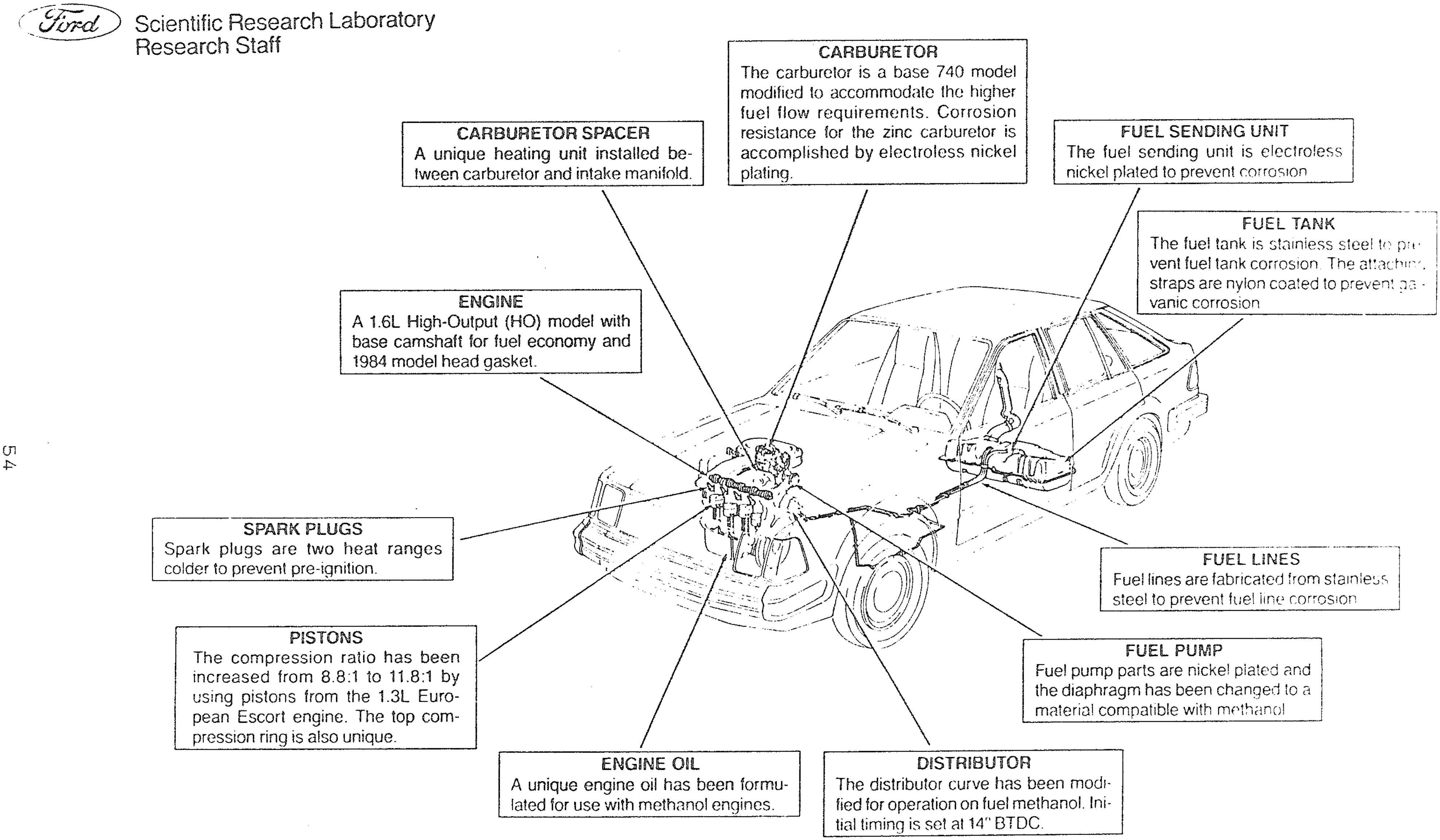

Ford
Scientific Research Laboratory
Research Staff
CARBURETOR
The carburetor is a base 740 model modified to accommodate the higher fuel flow requirements. Corrosion resistance for the zinc carburetor is accomplished by electroless nickel plating.
CARBURETOR SPACER
A unique heating unit installed between carburetor and intake manifold.
FUEL SENDING UNIT
The fuel sending unit is electroless nickel plated to prevent corrosion
FUEL TANK
The fuel tank is stainless steel to pre- vent fuel tank corrosion. The attaching straps are nylon coated to prevent gal- vanic corrosion
ENGINE
A 1.6L High-Output (HO) model with base camshaft for fuel economy and 1984 model head gasket.
SPARK PLUGS
Spark plugs are two heat ranges colder to prevent pre-ignition.
FUEL LINES
Fuel lines are fabricated from stainless steel to prevent fuel line corrosion
PISTONS
The compression ratio has been increased from 8.8:1 to 11.8:1 by using pistons from the 1.3L European Escort engine. The top compression ring is also unique.
FUEL PUMP
Fuel pump parts are nickel plated and the diaphragm has been changed to a material compatible with methanol
ENGINE OIL
A unique engine oil has been formulated for use with methanol engines.
DISTRIBUTOR
The distributor curve has been modified for operation on fuel methanol. Initial timing is set at 14" BTDC.

FIGURE 2.10

started by Ford Motor Company, and others, on the use of alcohol and diesel blends [29]. Obviously, there is a significant technological data base which suggests that the U.S. could begin serious production of methanol/ethanol vehicles in the next 5 to 15 years (near term).

Table 2.2.2 summarizes the NAU research team selection of the most likely AE replacements to gasoline transportation systems for the immediate, near term and long term time frames.

ALCOHOLS, ALCOHOL BLENDS	(Immediate to Near Term- 0 - 5 years)
DUAL FUEL (CNG/GASOLINE) CONVERSIONS, DEDICATED CNG	(Near to Medium Term - 5 - 15 years)
HYDROGEN	(Long Term - 15 - 25+ years)

TABLE 2.2.2 MOST LIKELY AE SYSTEMS

2.2.3 CNG: THE MOST PROMISING AE ALTERNATIVE FOR ARIZONA

The most promising AE alternative for the State of Arizona appears to be the CNG dual fuel conversion system. The results of the demand/penetration study, contained in sections 5, 6 and 7 of this report, indicate that of all of the potential AE systems surveyed the CNG dual fuel conversion system was the only AE system which Arizona drivers were willing to pay above standard vehicle prices for. In part the preference for a good dual fuel vehicle capability may be due to the senses of security associated with being able to choose from either systems in case of a future energy crisis. From a technological point of view the CNG energy source also offers many more advantages than disadvantages.

CNG as a motor vehicle fuel is currently being used on a large scale in Italy, New Zealand and Canada [30]. All of these countries have used tax incentive programs as seed money for the development of public refueling stations and for conversion of existing petroleum fuel vehicles. To a lesser extent the U.S. is using CNG, but in most applications this is limited to private fleet vehicle conversions and the lack of public refueling stations presents a current drawback for the private consumer. A 1982 report by the American Gas Association [16] indicated that the costs of running CNG vehicles as compared to gasoline powered vehicles were on the average 39% cheaper to operate. The average cost of converting a gasoline fueled vehicle to a dual fueled (gasoline and CNG) is approximately $1,500 dollars. This includes all of the necessary hardware needed to run the vehicle on both fueling sources. As a rough estimate of the refueling site costs, $1 per displaced gallon of gasoline can be used (i.e. if 40,000 gallons of gas used per year were displaced by 40,000 equivalent gallons of CNG the cost of the refueling site would be approximately $40,000) [16]. A gallon of gasoline has the BTU energy equivalent of about 108 cubic feet of natural gas. When compressed at a pressure of about 2600 psi the natural gas occupies about 1 cubic foot of space. Natural gas is the largest domestic source of energy in the U.S. and it currently accounts for 31% of the primary U.S. energy consumption. The American Gas Association (AGA) reported in 1980, that the proven reserves amount to 195 trillion cubic feet, in addition to this the AGA estimates that an additional 1000 trillion cubic feet are available for recovery. The current yearly consumption in the U.S. is about 17 trillion cubic feet. Experts in the industry estimate the U.S. has a known 60 year supply, based on current use levels. These estimates don't include the vast reserves of Mexico and Canada or the extraction of natural gas from unconventional sources such as tight sands, devonian shales, coal seams and geopressured aquifers. The potential for synthetic natural gas produced from coal is still being explored, however, current U.S. funding levels for synthetic fuel projects is declining due to the effects of energy conservation, lower gasoline prices, and increased supplies of gasoline.

CNG is a relatively new fueling source in the U.S. and as such most areas of the country have not adopted regulations governing the installation of retrofit vehicle equipment or the refueling site. American Gas Association, has published a proposed set of regulations (NFPA #52). These regulations outline the design of equipment and the building of the refueling site. The CNG fuel cylinders are regulated by the U.S. Department of Transportation and must be hydrostatically tested every 5 years, to insure their continued safe operation.

Each cylinder is equipped with a safety device referred to as a burst disc, with a fusible material. The fusible material is an alloy which will flow when the temperature reaches 100 degrees centigrade (212 degrees fahrenheit) and the burst disc is designed to rupture at a pressure of 3775 psi which will allow the gas to escape. The alloy will flow, allowing the burst disc to rupture if the pressure reaches 3775 psi. The burst disc installed in these cylinders is made of inconel material which is impervious to etching of natural gas. If replaced they should be of like material to prevent future failure resulting in leakage.

In addition to the above, the cylinders must be labeled with the words "CNG ONLY" in letters at least 1 inch high in contrasting color and in a location which will be visible after installation.

The cylinder cost averages approximately $67.00 per gallon of compressed natural gas (CNG) or about $1,000.00 dollars for the same range of a conventionally fueled vehicle [16]. Since in most vehicle applications the on board CNG capacity is limited to the average daily driven mileage, the cost of the cylinders can be determined by taking the average number of miles driven divided by the vehicles average mileage per gallon and multiplying this by $67.00.

The total conversion price per vehicle will average $1,500, inclusive of all necessary equipment for conversion to dual fuel capacity. The dual fuel capacity is a bonus because it allows the user to choose the most economical fuel source.

Compressed natural gas achieves close to the same mileage as a conventionally fueled vehicle so the number of equivalent gallons of CNG required is limited by the necessary required range.

Because natural gas is lighter than air, there is no risk of pooling of the spilled fuel as compared to petroleum fuels. The dissipation of natural gas (because it's lighter than air), and the limited fuel to air mixture required for combustion, all but eliminates the possibility of explosion. A double redundant design being used in modern CNG cylinders eliminates the possibility of the cylinder becoming a "bomb" and exploding in the event of an accident. The gasoline fuel tanks of a dual fuel vehicle are substantially more dangerous than the CNG cylinders. The equipment necessary for conversion is usually purchased in a package from a CNG equipment supplier. Included will be the compressed gas tanks, the pressure regulator, fuel selection solenoid and gas mixer. The refueling station equipment should include compressor, cascade (if quick fill), refueling stations and the related safety equipment. Again, this is usually purchased in a package and can be custom tailored to the individual needs of the consumer [31].

CNG is a clean burning fuel when it is burned, CNG produces half the amount of nonmethane hydrocarbons as gasoline. The majority of the emissions from a CNG powered vehicle are simple water vapor. Emissions are discussed in more detail in Section 2.3. Both the Ford Motor Company and Toyota have initiated production on a limited number of CNG only light trucks. More details are given in Section 4 of this report under the marketing section. Figure 2.11 illustrates some of the features of the Ford CNG truck.

There are two basic types of refueling systems, fast fill and slow fill, but combinations are frequently utilized depending upon the needs of the end user. The fast fill system will fill the vehicles in about the same time as a conventional (gasoline) filling system. The slow fill system is designed for the user that has a vehicle that returns to the fueling site for extended periods of time, usually 8-12 hours. Both systems require compressors and the necessary piping for the transfer of the compressed gas to the vehicles.

The fast fill system cost includes the compressor station and the necessary high pressure storage system. The advantage of the fast fill system is it allows for refueling of the vehicles without having to remain at the refueling site for extended periods of time. A disadvantage is that the time between vehicle

The natural gas-fueled Ford Ranger shown on the right was engineered by Ford Motor Company at its Scientific Research Laboratory in Dearborn, Michigan. The diagram shows the unique components. The natural gas Ranger is part of Ford's continuing worldwide research effort to develop vehicles capable of operating efficiently on alternative fuels. Ford sees vehicles operating exclusively on natural gas as a cost-saving option for fleets where vehicles return to a central base each day.

Natural Gas Benefits

Compressed natural gas offers several potential advantages over gasoline as an engine fuel:

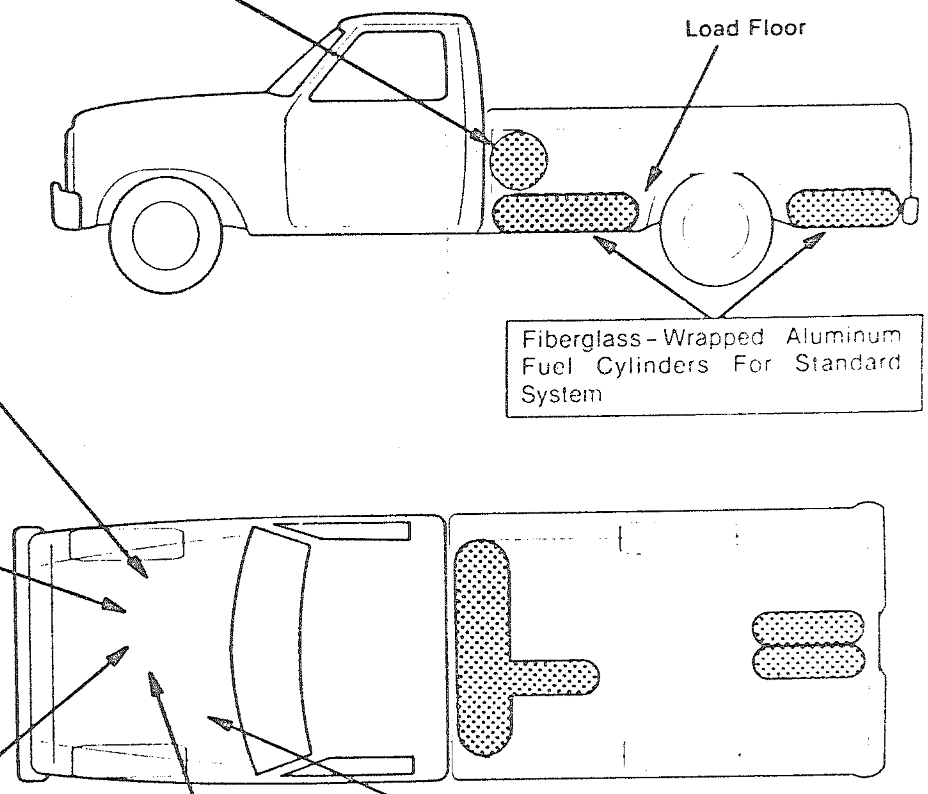
- Lower fuel costs
- Longer engine life
- Reduced maintenance costs
- Smoother engine operation

Natural Gas Inhibitors

There are some drawbacks to universal application:

- Refueling Station investment costs
- Limited vehicle range

Fuel Economy (Auto Trans.)	Natural Gas Ranger	Gasoline Powered Ranger
EPA City Cycle	21 mpg	22 mpg
Performance 0-50		
Seconds	13.0	12.7
Range (@ 3000 psi Fill Pressure)		
Standard Fuel System	— 125 miles	
Extended Range System	— 225 miles	



Ford Scientific Research Laboratory
Research Staff

FIGURE 2.11

refueling determines the compressor capacity needed, thus the shorter the time span between refueling the greater the compressor capacity required. A typical fast fill system will cost anywhere from $60,000 to about $120,000.

The equipment required for a fast fill system includes:

1) Compressor: this boosts the pressure of the natural gas from delivery pressure of about 5 psi to 3600 psi. The suppliers of compressors are varied and the compressor chosen should meet the refueling demands of the end user. A typical vehicle converted to CNG with 2 storage tanks has the capacity to store 700 cubic feet of natural gas at 2400 psig. To fill within 10 minutes a vehicle whose tanks are empty would require a compressor of 70 cfm capacity. This would only allow 6 vehicles per hour to be refueled. By adding storage containers that could be filled in advance a downsized compressor could be utilized. The compressor capacity needed is larger than that required for a slow fill station.

2) High pressure gas storage containers: these are commonly called a cascade. The cascade is a group of cylinders equally divided into three separate zones low, medium and high pressure, these zones are interconnected so that the cascade operates as one unit. The cascade zones are initially filled with CNG in sequence by the compressor to the normal operating

pressure of the system. The highest pressure zone is refilled first followed by successively lower pressure zones. This sequence is called priority fill. These zones allow for multiple vehicle refueling without drawing directly from the compressor. The cascade gives the user the equivalent of a gasoline storage tank on which to draw for refueling vehicles. The cascade is directly connected to the compressor and the zones are interconnected with pressure regulators and safety devices. The size of the cascade can be scaled to the amount of fast fill stations needed.

3) Refueling station: the size and location is determined by the users needs. The station looks like a typical gasoline refueling station except instead of pumps quick fill hoses for connection to CNG vehicles are in place.

The slow fill system is designed for the fleet user whose vehicles experience extended periods of time between the need for refueling. Because the refueling process requires between 8 to 12 hours (or more depending upon the compressor capacity) the need for parking facilities for connection to the slow fill system is required. The size of these facilities depends of the number of vehicles to be refueled at one time. It is possible to establish the refueling capacity in the existing company vehicle parking area. The slow fill system, because of the extended time required for refueling needs, needs only the compressor with the necessary pressure regulation equipment to determine if the vehicles have completed refueling and the connections for transferring the CNG to the vehicle. Slow fill systems can cost anywhere from $600.00 to $10,000. The obvious cost savings are apparent.

The mix fill station allows the user to custom tailor the refueling operation to the projected needs.

A new application of an old product has been introduced by Dual Fuel Inc. of Montebello, California, it is the Haskel CNG amplifier system. This pump eliminates the first two compressor stages by using the high pressure gas line (usually around 350 psi) to drive the pump and compress the natural gas. The problem with this type of pump is that the user must be located near a gas supplier's high pressure line and be able to discharge the "used" (lower pressure, around 60 psi) back into the distribution system.

The complete installed costs for a fast, slow or mix fill station depends on the needs of the user and the logistics of the refueling site.

2.2.3a HOME UNIT (SLOW FILL) CNG SUPPLY

The major drawback or disadvantage associated with dedicated CNG or CNG duel fuel conversion systems in Arizona is that there are no natural gas compression or fill-up stations available to the general consumer. One possible means for overcoming the above problem would be through the use of an overnight slow fill home refuel system which compresses the natural gas supplied to the residence. As noted in reference 32, this method of general consumer refueling of CNG powered vehicles would take advantage of the existing and well-developed residential system of natural gas. The city of Phoenix for example has a very good grid work of high passive natural gas lines (about every mile) which feed the low pressure (5-7 psi) residential units. Currently more than 40 million homes in the U.S. use natural gas and the number is expected to rise due to the low cost of natural gas as compared to heating oil.

The concept recommended by Dr. Vadim Kopytoff at the June 1984 NAU/ADOT research project review meeting and also advocated by Dr's Amos Golovoy and Roberta J. Nichols of the Ford Motor Company [32] would use a multi-stage home compressor unit to compress the natural gas from the home gas system into fuel storage cylinders on the vehicle. For safety purposes the compressor and fill station should be located in an open area. The compressor must be capable of pressuring the natural gas from about 5 to 7 psi at the incoming service line to the desired storage pressure in the vehicle tanks, which would vary between about 300 to 2400 psi.

Costs for the higher performance multi-stage compressors capable of achieving several 1000 psi pressure would be in the neighborhood of $10,000.00. Lower cost units with lower pressure capabilities limit the range of the vehicle. Selection of a unit would depend on factors such as reliability, and safety. In any event, home fill units, while not inexpensive, are available and if prices of these compressor units drop in the next few years the home fill method of CNG could become feasible.

2.2.3b DUAL FUEL CAPACITY

Dual fuel capacity is the combination of the existing fuel system with CNG. Since CNG is able to use the same engine designs as conventional fuels the end user is allowed the option of choosing the most economical fuel source.

The range of a CNG powered vehicle is limited to the amount of fuel carried on the vehicle. This limitation can be overcome by installing more CNG tanks, but in most vehicle applications space is at a premium. The on board storage requirements should be limited to the amount of fuel needed for average daily use. By including the existing fuel system the end user is allowed the margin of safety to go over the average daily use.

A problem with keeping the dual fuel capacity as compared to utilizing only a dedicated (CNG only) vehicle is the weight differential between the two systems. The weight difference is minimal but could effect the mileage on smaller vehicles, but the savings in fuel costs in most instances will overcome the space and weight problems.

2.2.3c DUAL FUEL CONVERSION COSTS

The cost for converting a vehicle depends upon the vehicle type, the amount of load carried and the desired range. The cost of the conversion kit not inclusive of the labor needed to mount it varies between $400 and $500 dollars. The conversion kit includes all of the necessary hardware to convert the existing gasoline or diesel system to a dual fuel capacity. The components of the conversion kit include:

1) The natural gas fill: valve the connection from the refilling station to the onboard cylinders. This valve is designed as a "break away" valve. It shuts off the flow of gas if the vehicle drives or rolls away from the refueling site.

2) High pressure fuel line and the master manual shut-off valve: these transfer the high pressure gas to the pressure reducer and allows the user to manually shut off the CNG supply to the engine.

3) Pressure reducer: this reduces the high pressure gas (2400-3000 psi) to atmospheric pressure. It is a three stage reducer combined into one unit. The first stage reduces the cylinder pressure from 2500 psi to 35 psi, the second stage reduces the pressure from 35 psi to .015 psi, the third stage meters the gas into the engine according to the requirements of engine speeds and load. This device governs the flow of gas that when combined with air in the fuel mixer will reach the

engine manifold.

4) Natural gas solenoid valve: this shuts off the natural gas to the engine when it's not running or the vehicle is running on gasoline. The solenoid valve is usually equipped with a natural gas shut-off delay for switching from CNG to other fuels. This eliminates stall when switching fuels.

5) Natural gas mixer: allows for correct fuel to air mixture before ingestion into existing vehicle carburetor. The mixer operates on the diaphragm controlled, variable venturi principle and meters the correct volume of natural gas into the air stream over the full range of engine air-flow demands [31].

6) Fuel selection switch: located inside passenger area of vehicle. It allows the driver to choose the type of fuel to run the vehicle on.

7) Dual curve ignition timing box: this advances the timing of the engine 15 degrees automatically (tied into the fuel selection switch) to optimize the fuel chosen for maximum performance.

In addition, $200 should be budgeted for labor and miscellaneous parts per vehicle.

The conversion price does not include the cost of the compressed gas cylinders. Cost run about $67.00 per gallon equivalent of gasoline. Therefore, if the equivalent of 6 gallons of gasoline or about 120 miles range are desired, the cost would be about $400.00 for the storage cylinders. These cylinders can be constructed of either plain steel, fiber wrapped steel or fiber wrapped aluminum. The fiber wrapped aluminum and steel cylinders have the advantage of greater capacity with reduced weight. These cylinders are designed to operate up to 3000 psi, and incorporate a double redundant safety feature that eliminates the possibility of explosion. Each cylinder has a legend stamped into the neck portion of the cylinder. The explanation of the legend is given by the following example:

Example: D.O.T. 3AA 2400 (Printed Legend Stamped on Bottle)

D.O.T. is the Department of Transportation or regulating body with control over certification and manufacture of cylinders. 3AA indicates the grade of material used to manufacture.

2400 indicates working pressure of the cylinder at 21 degrees centigrade (70 degrees fahrenheit).

PSI indicates manufacturer's code as registered with the D.O.T.. Numerals are serial numbers of cylinders. These are for record keeping purposes.

The date of certification is stamped on each cylinder by an independent third party. Each cylinder must be recertified by the end of each five year period.

2.3 HYDROGEN AS A POSSIBLE FUTURE AE SYSTEM

Hydrogen, in a hydride composition, appears to be very promising for an AE transportation system. Several research studies have been completed which demonstrate the technical feasibility of using hydrogen as an AE replacement for gasoline [26, 33]. Figure 2.9 illustrated the currently available high energy density of hydrogen as compared to unavailable energy density levels of future battery designs. Other advantages of hydrogen include its availability, recyclability, desireable combustion characteristics and clean burning characteristics. The hydrogen energy source has been adapted to standard IC spark ignition engines by Zavaleta [26], through the use of a rather simple hydrogen/air metering device. The performance of the hydrogen powered IC engine modification was actually better than the same engine performance when run with gasoline, the original fuel source for that particular engine design [26]. Figure 2.12 illustrates the Zavaleta hydrogen/air metering concept (H_2 design[3]) V-8 SI engine. Figures 2.13 and 2.14 demonstrates the road performance characteristics of the various Zavaleta hydrogen concepts versus the gasoline powered version of the engine.

Combustion of hydrogen and air results in by-products of water and a very small amount of nitrous oxide, thus giving a clean burning fuel. Energy density by mass shows a three to one advantage of hydrogen over gasoline; however, based on the energy density by volume the hydrogen is not quite as promising a fuel source over gasoline due to the lower heating value of the

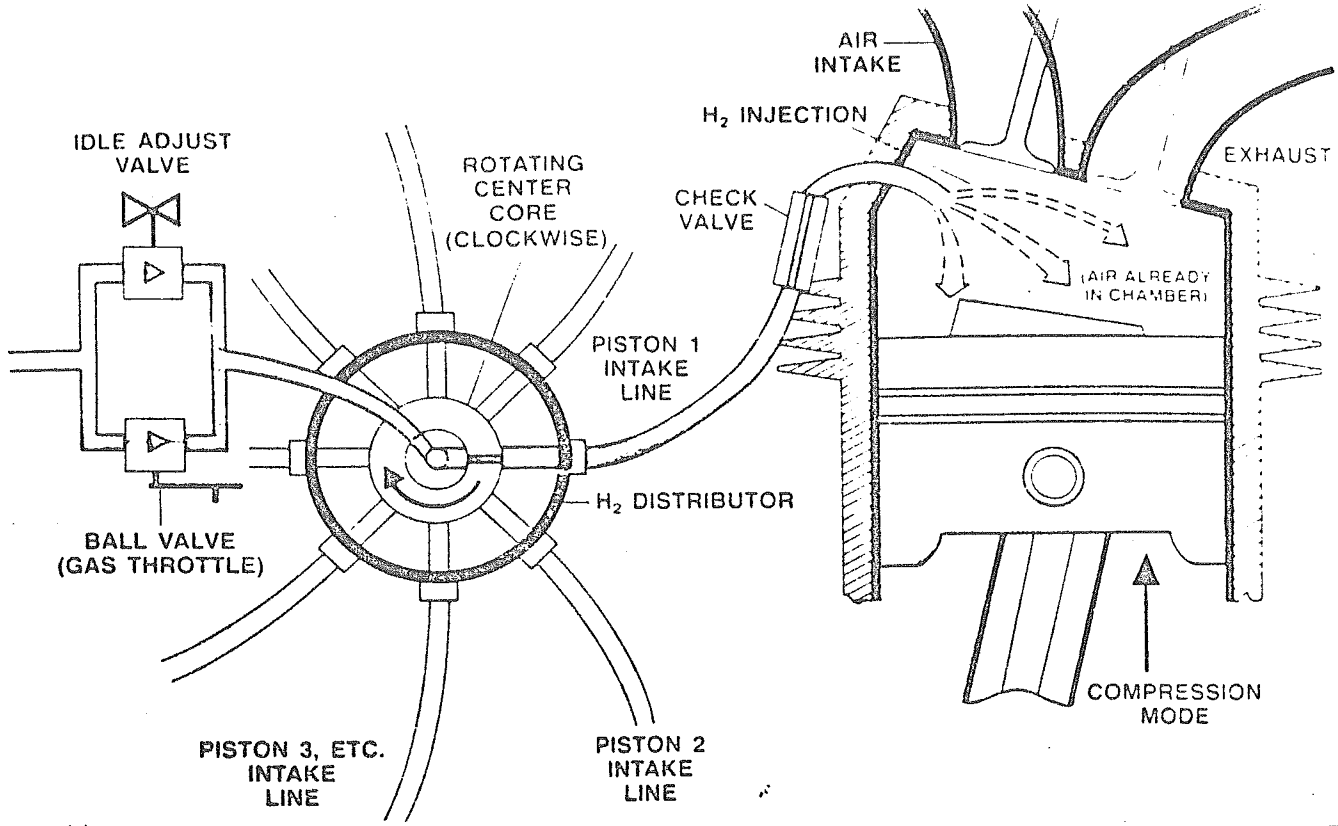


Fig. 2.12A Direct Cylinder Injection Schematic of Hydrogen Engine Design-3

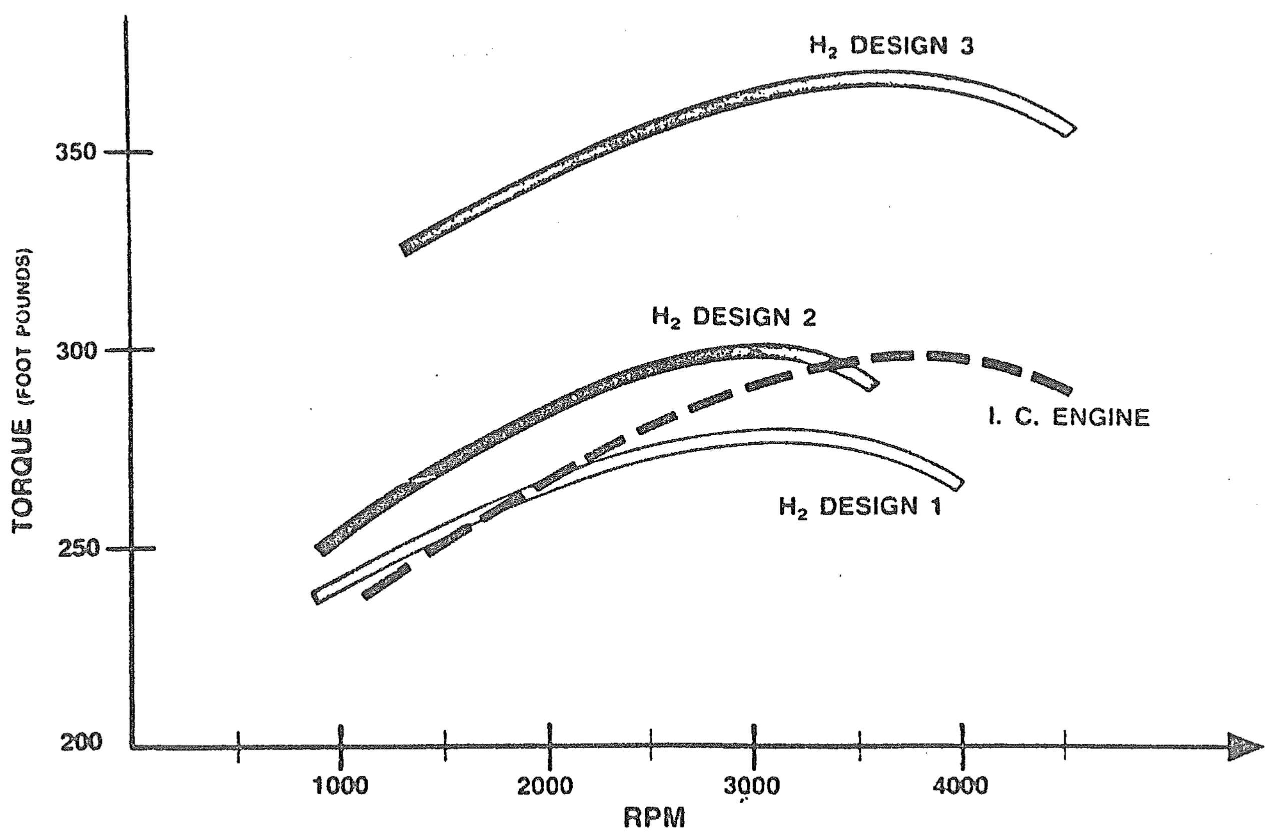


Fig. 2.12B Torque vs RPM Engine Performance Curves

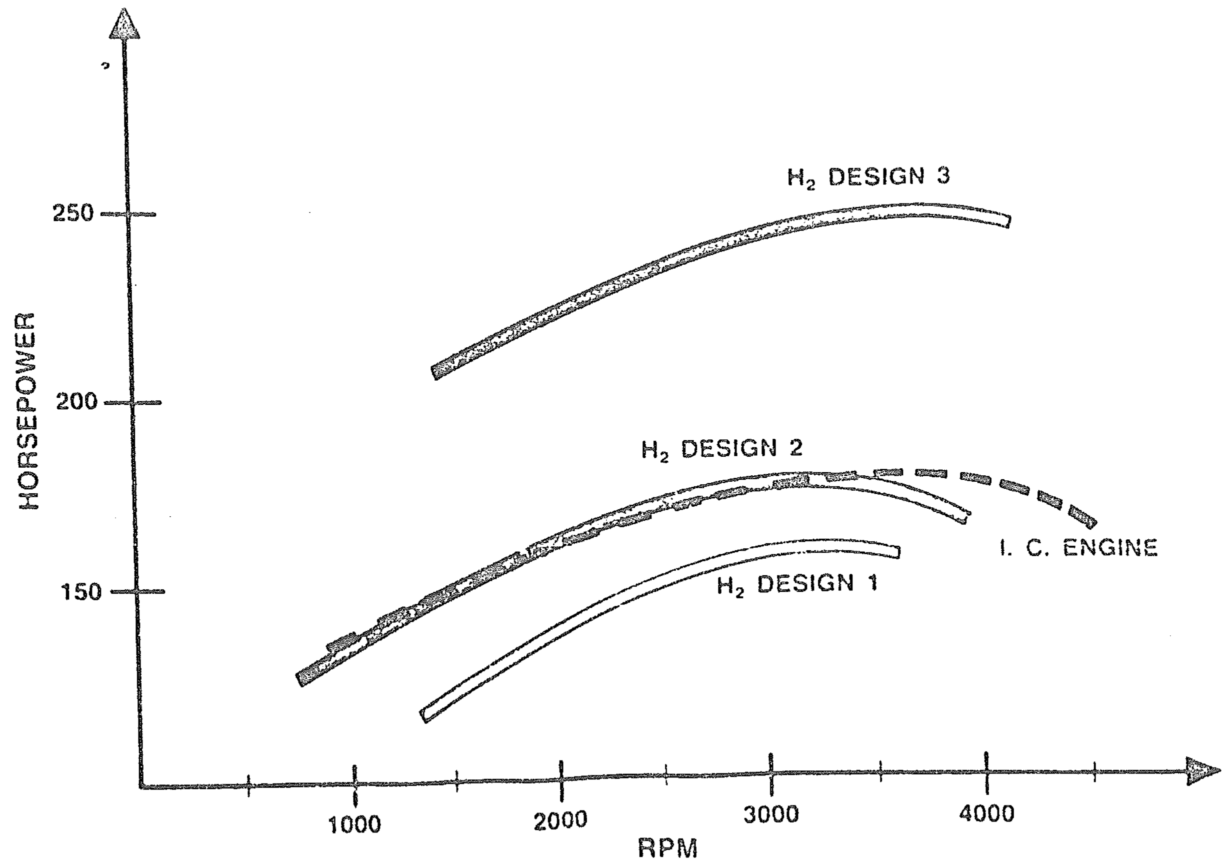


Figure 2.13 Horsepower vs RPM Engine Performance Curves

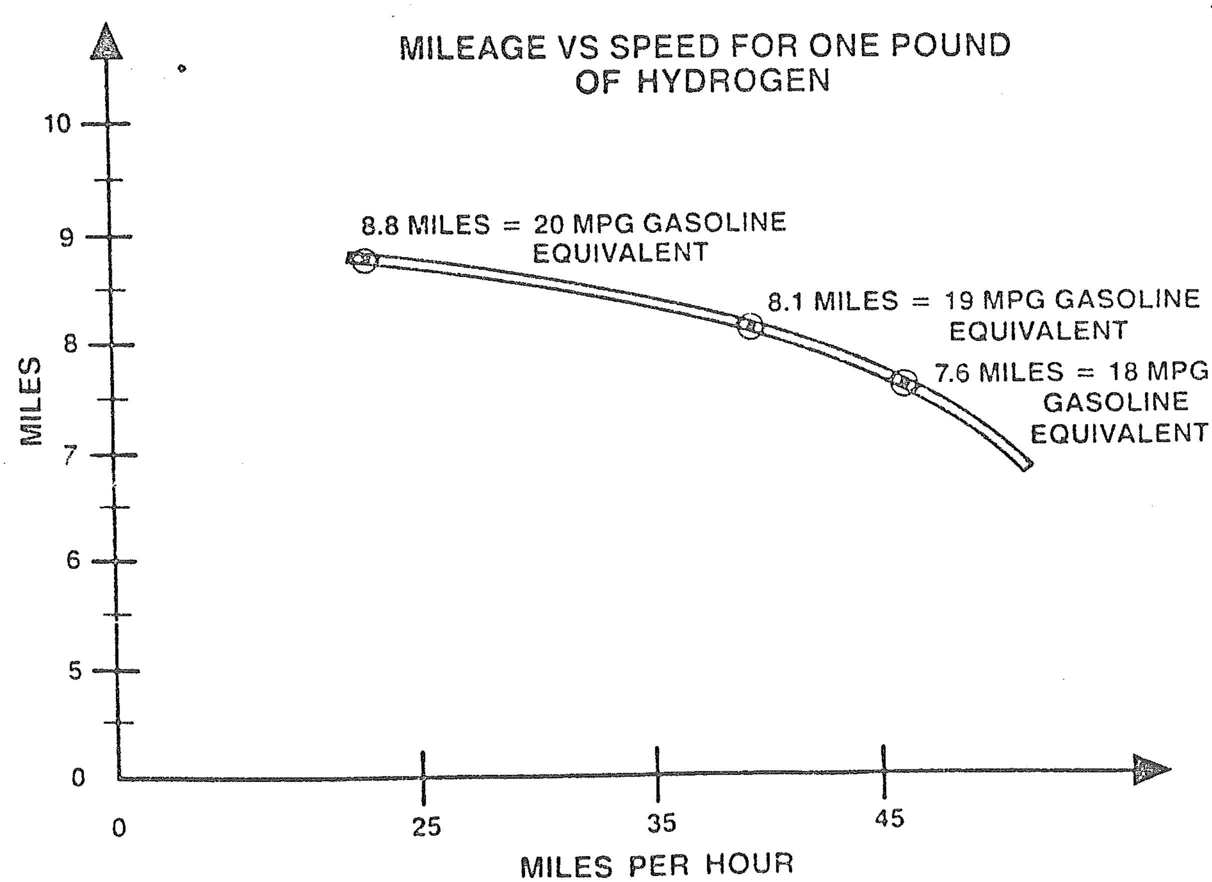


Figure 2.14 Continuous Speed Performance for Hydrogen Engine Design-1

hydrogen. Flammability limits for hydrogen are greater than for gasoline, thereby resulting in a much larger range of fuel mixtures for which a hydrogen engine can operate. In addition to the above, hydrogen also possesses a faster flame speed and lower ignition energy than does gasoline, thus resulting in more favorable combustion characteristics when compared to gasoline. Table 2.3.1 provides a comparison of key properties of hydrogen versus isoctane (gasoline).

TABLE 2.3.1

	H_2	Isooctane
ENERGY DENSITY (Mass)	61,000 $\frac{BTU}{LB}$	20,500 $\frac{BTU}{LB}$
ENERGY DENSITY (Volume)	320 $\frac{BTU}{FT^3}$	950,000 $\frac{BTU}{FT^3}$
FLAMMABILITY LIMITS	Vol % in Air	
(lean)	4%	1%
Range		
(rich)	75%	6%
FLAME SPEED	180 cm/sec	40 cm/sec
MINIMUM IGNITION ENERGY	.02 MJ	1MJ

PROPERTIES OF HYDROGEN AND ISOOCTANE

Also, experience has shown that flammable fuels and gases, such as gasoline, propane, methane, and hydrogen, can be handled safely when suitable precautions are taken [34]. In comparison to other fuels, hydrogen does present a hazard because of its wide range of flammability and its low spark ignition energy as shown in Table 2.3.1. Furthermore, hydrogen is more likely to leak from containers than would other fuels or gases due to the obvious small molecular size of the hydrogen and the resulting low viscosity of the gas. Thus, safe containment and protection from sparks or other ignition hazards are essential in the design of a crashworthy hydrogen powered vehicle.

Data from reference 35 indicates that the cost for hydrogen production ranges form 31 to 61 cents per pound of gas. Based on an energy equivalent basis it is calculated that 2.2 pounds of hydrogen would be equivalent to 1 gallon of gasoline for the lowest performer of the hydrogen engine designs ("H_2 Design-1") and therefore even in the least promising design the equivalent cost per gallon for the hydrogen would be $1.34 or about 6.7 cents per mile. For the improved "H_2 Design-3" the cost per mile for hydrogen would be about 4.5 cents per mile which is comparable to some of the figures cited in the hydrogen AE study conducted by Kukkonen [33] of the Ford Motor Company. Kukkonen is not very optimistic about the future of hydrogen as an AE transportation replacement to gasoline. His study provides an excellent overview of the differences in costs for hydrogen and electric vehicle designs of various weights, ranges, system efficiencies and methods of obtaining hydrogen and electric energy sources. One factor which has not been covered thoroughly however, in reference 33 is the effect of improved efficiency in IC engines through the use of ceramics and other high technology materials which are being researched and utilized by several Japanese automotive engine manufacturers. This technology, would be applicable to any of the AE sources cited in this report that are adaptable to the IC engine. While the hydrogen AE source is a long way off (say 25 + years) it is not likely to be 100 years away as suggested by Kukkonen.

2.4 COST, SAFETY AND EMISSION BENEFITS OF THE MOST LIKELY AE SYSTEMS

As noted in Section 1.1, a major problem in the Phoenix and Tucson urban/metropolitan areas deals with the environmental pollution caused primarily by gasoline powered vehicles. Air quality standards were violated in both cities during the winter of 1985-86. The above violations could lead to significant loss of federal revenues for state projects. By considering the encouragement of the most likely AE systems identified in Section 2.2 of this report the State of Arizona could gain much greater benefits than would be possible by fuel taxes or vehicle registrations.

First of all, with regard to fuel costs the AGA has published data which indicates that natural gas is a more cost effective AE replacement to gasoline if a vehicle is driven more than 15,000 miles annually. This information is shown in Figure 2.15, along with comparison of fuel costs for propane (LPG), methanol, and electric vehicles. By far, the CNG fuel either in a dual fuel mode or in a dedicated mode can provide cost savings to the consumer and ultimately to the State of Arizona through drastic reduction of hazardous emissions and gasoline pollution products. The cost for CNG vehicle fuel at the present time is billed by Southwest Gas of Tucson on a large industrial customer rate. Southwest Gas is leaning toward creating a new rate structure that would accurately reflect the cost of delivering the gas to the customer. The cost of providing CNG as a motor vehicle fuel is less than the cost of delivering the gas to a housing subdivision or an industrial customer. The amount of fuel consumed by the average vehicle is approximately the same amount as delivered to three medium size houses. The obvious cost savings to the gas supplier can be passed on to the consumer once new rate structures are in place.

Currently neither the State of Arizona or the federal government have the means of collecting taxes on CNG as a motor fuel. The current users are figuring in the equivalent taxes in the total costs of the CNG and are placing the uncollected tax into a reserve fund in case the motor fuel taxes are ever applied. The projected cost of the motor fuel tax is 13 cents per gallon. This is the same amount of tax that is currently levied on gasoline and diesel.

2.4.1 FUEL SAVINGS

The current fuel savings of CNG when compared to the costs of conventional fuel (i.e. gasoline, diesel or LPG) range from 5 cents per equivalent gallon to 40 cents. The cost savings are influenced by the supplier of the natural gas, capital costs and electric rates. Scottsdale, Arizona is currently saving approximately 13 cents per gallon where as Southwest Gas of Tucson is saving between 25 to 30 cents per gallon. The cost savings for an average vehicle getting 18 miles per gallon driven for 12,000 miles per year, based on the average savings of 26.5 cents per equivalent gallon would be $176.67 dollars per year. If the life of the vehicle were considered to be 125,000 miles the total projected cost savings (assuming both natural gas rates and gasoline cost remained the same or increased proportionally) would be $1840. As the spread between the costs of natural gas and gasoline increase the amount of fuel savings would rise also. If the amount of mileage driven per year is increased the fuel cost savings would rise proportionately.

2.4.2 FEDERAL, STATE AND LOCAL REGULATIONS

The federal Department of Transportation regulates the tanks used for CNG compliance with current compressed gas regulations, the end user comes in contact with these regulations by means of hydrostatic testing of the tanks every 5 years. The testing is required to insure that the tanks will operate safely in every day use. All of the major dealers of CNG tanks sell only tanks that conform to existing DOT regulations. The fueling system of the vehicle must conform to the regulations governing gasoline or diesel fuels. The major difference is the cut off switches that cut off the natural gas supply when switching fuels. The setup and the maintenance of the refueling station comes under local building and fire regulations.

2.4.3 ENVIRONMENTAL CONCERNS

CNG is a clean burning fuel, (see Figure 2.15) the amount of non-methane hydrocarbons produced are half that produced by gasoline. The lack of the hydrocarbons in CNG emissions means that the level of smog produced is smaller. CNG exhaust contains almost no carbon monoxide, sulphur or suspended particulates, all of which are found in abundance in gasoline, LPG and diesel exhaust. In fact, most CNG fuel exhaust is made of simple water vapor. The weather and the climate do not seem to present a major problem for dual fuel vehicles. Cold weather starting is enhanced due to CNG's vaporous state. Some problems in the fuel delivery system due to cold weather have been experienced by some users. For example, the grease in the pressure gage system will thicken and give a false low pressure reading until the system warms up. Circulating the engine coolant around the first stage of regulation seems to eliminate this problem.

Maintenance of the refueling site in cold weather should also be taken into account. The user in cold weather climates might want to inclose the compressor station for easing regular maintenance.

Figure 2.15

Emissions of Alternatively Fuel Vehicles (grams/mile)					
Fuel	Non-Methane				
	HC	CO	NOx	SOx	Particulates
Compressed Natural Gas	0.26	0.03	1.23	Neg.	Neg.
Gasoline	0.54	8.35	1.92	0.71	0.08
Methanol	0.25	2.90	0.55	Neg.	Neg.
Electricity	0.03	0.10	2.28	1.58	0.04

Assumes 80% of SOx removed in fossil fuel electric generation. Assumes 95% of particulates removed in fossil fule electric generation. Emissions attributed to battery recharging of electric vehicles are not included.

2.4.4 VEHICLE COMPARISONS

A) Types of Vehicles:

CNG alternative fuel conversions on all types of vehicles, ranging from small cars with 4 cylinder engines up to vehicles having 22,000 pounds gross vehicle weight have been successfully accomplished in recent years. The rear suspension of the smaller vehicles may have to be enlarged to compensate for the additional weight of the CNG cylinders. The dedicated vehicle allows the user to take advantage of the lower cost of natural gas and can eliminate the additional weight caused by incorporating dual fuels. If the vehicle manufacturers make the decision to produce a dedicated vehicle the cost should be comparable to that of a gasoline powered vehicle. Because CNG vehicles require no pollution control equipment to conform to present emission standards or a catalytic converter, the cost savings could also be passed on to the consumer.

B) Range:

The range of the CNG powered vehicle is limited by the amount of fuel carried on board. Space seems to be the main limiting factor due to the size of the CNG tanks. If the vehicle is converted to run on only natural gas and the existing conventional fuel system is removed, the CNG tanks can be placed where the gas tank was located. The major vehicle manufacturers are expressing an interest in manufacturing a dedicated CNG vehicle. Ford Motor Company has manufactured 20 Ranger pick-up trucks for testing the feasibility of CNG design. The Ranger pick-ups were distributed to natural gas company fleets to study the effect of CNG as a motor fuel. Toyota has plans to introduce a dedicated CNG vehicle to the United States market.

C) Power:

There is no significant loss of power when compared to conventional fuels if the engine is in good working condition. The user may notice a slight lagging when accelerating on CNG. This can be over come if the engine is tuned correctly (to the vehicle manufacturers specifications) and the difference in timing is taken into account. To be correctly timed to take advantage of the burn properties of CNG, the engine timing should be advanced 15 degrees. This is due to the faster burn rate inherent in natural gas. The increased weight of the dual fuel vehicle will have an effect on smaller vehicles but is unnoticeable in larger cars and trucks.

D) Engine Life:

Since CNG has an octane number higher than gasoline (around 130) its use in high compression engines poses no problems and will operate without pre-ignition. The elimination of "knock" with out the addition of lead as an anti knock reduces the build-up of carbon in the engine. The oil life is extended because the CNG is not mixing with the oil.

This allows for an extended life of the viscosity of the oil. The engine life can be increased by 150 to 200 percent using CNG. The decrease in maintenance costs should be taken into account when deciding to convert to CNG.

E) Driving Patterns:

Since there is a lack of currently available public refueling stations the most likely early application of CNG vehicles is for fleet operators that are based out of a central location. The costs of the refueling site can be minimized if duplication can be avoided. The location of the refueling site should be as close to the center of the company's range of business as possible. This will allow the CNG user to limit the amount of CNG carried on board the vehicles, thus reducing the cost of CNG cylinders. The choice of refueling systems should include considerations of the number of vehicle refueling per day. If the CNG user can afford the amount of cylinders per vehicle to provide enough natural gas for average daily use, a slow fill system can be utilized. If the vehicles will require more than one refueling per day a fast or mix fill system will have to be used.

F) Mileage Limitations:

Typical CNG cylinders can hold between 300 to 1000 cubic feet at 3000 psi. Depending upon the size of the vehicle and the number of cylinders a typical 2 tank installation will provide from 60 to 200 miles of range. If the vehicle is dual fuel the addition of the gasoline mileage must also be taken into account. If the vehicle were designed as a dedicated vehicle the mileage provided would be comparable to that of a gasoline vehicle. The vehicle designed by Ford is rated at over 30 mpg with a 200 plus mile range.

G) Safety:

CNG vehicles are safer than petroleum fueled vehicles. Some of the reasons for the excellent safety record of methane-fueled vehicles, according to Dr. Winston Porters' 1979 10 year study are:

1) Natural gas is lighter than air, this eliminates the possibility of puddling in the event of an accident.

2) Natural gas is more difficult to ignite than gasoline or propane. The temperature of ignition for CNG is about 1300 degrees fahrenheit and for gasoline 800 degrees.

3) The required air to fuel mixture is quite limited usually in the range of 17 to 1. The large air to fuel mixture helps reduce the possibility of fire in the event that a CNG cylinder is ruptured.

4) Natural gas is non-toxic. The vehicle emissions contain negligible amounts of CO. This allows for the use of natural gas powered vehicles to be operated safely indoors.

5) The systems design strength.

If a leak in the CNG system should occur the natural gas will rise and dissipate into the atmosphere. The ignition point of natural gas is higher than gasoline usually about 1300 degrees as compared to 800 degrees fahrenheit for gasoline. The ignition point of CNG is so high that a cigarette will not ignite it. Insurance underwriters have recognized the safety of CNG and consider it to be as safe or safer than any other vehicle fuel.

2.4.5 SUMMARY:

CNG's use as a vehicle fuel is promising for the fleet user. It provides a clean alternative to conventional petroleum fuel basing and allows the dual fuel user to choose the most economical fuels and the reduced vehicle maintenance costs should be considered when the decision to convert is being made. The natural gas supply industry is showing an interest in helping the fleet operator with the conversion decision and the forecast domestic supply is over 60 years including projected growth rates. The cost of CNG should be expected to rise over the current rates due to supply and demand, but CNG should still show savings when compared to conventional fuels. The cost of conversion to CNG is significantly front loaded, but the end user must keep in mind that once the equipment is purchased the conversion kits on the vehicles may be removed and put to use on new or other vehicles in the company fleets. The refueling station can be used with all converted vehicles and replacement won't be needed for 20 years.

In areas of emission controls the use of CNG allows the user to meet the emission requirements without adding any additional equipment. The major component of CNG exhaust is water vapor, with a reduction of non-methane hydrocarbons.

SECTION 3

SOCIO-BEHAVIORAL CHARACTERISTICS

3.1 INTRODUCTION

3.1.1 THEORETICAL ORIENTATION

The acceptance and use of energy alternatives by the American public is a slow process which appears to be similar to the acceptance of any new technology or innovation. According to Rogers (1983) early adopters of innovation are 1) higher social status, 2) more educated, 3) have greater exposure or access to information, and 4) are more favorable to change and risk. Only 2.5% of the population are classified as "Innovative" or risk taking individuals (see Figure 3.1). These are unique individuals who implement innovation very early and appear to have more financial freedom than the "Early Adopters" (13.5%).

The diffusion of innovation perspective attempts to explain the adoption of new technologies by examining the attributes of the technology, the charac-teristics of the adopter, and the adoption decision process. These factors determine the rate that the new technology progresses through the five adoption stages (from innovative to later adopters).

Rogers emphasizes that change in adoption is caused by reduced uncertainty about the product due to increased interpersonal communication about its value.

A more complete explanation of the innovation process was proposed by Schnorr & Levi (1983). In the two-stage process, the image of the technology becomes transformed from a statement of passive personal values to the active participation in a social process. The early adopters use the image to make a statement about themselves to society. As the image is accepted by society (or rejected) it becomes institutionalized. By focusing on the image and its transformation, many of the potential failures can be understood and avoided.

During the first stage of adoption, the image reflects the personal values as well as economic, social and environmental values of the adopters. In many cases, it is not economically rational to adopt a new technology. The product is still under development so its reliability is uncertain and its cost is high due to a lack of mass production. Although some early adopters are risk oriented capitalists, most do not act like risk oriented entrepreneurs in other areas of their life. People "rationalize" their investment by misestimating the technology's reliability and payback.

The social status value of a new technology relates to the fashion pro-cess. In a country where technological progress is a widely held ideal, displaying the adoption of a new technology creates the potential of becoming a trend setter. Trend setting involves a limited number of people for a limited duration, eventually the fashion/fad either takes off or disappears.

Both the economic and social justifications for adopting a new technology are types of "egoistic" values: innovations are adopted because of the benefits which the individual receives. A third factor is the environmental or "altruistic" values which innovation represents. Adopting innovations is a statement about an individual's view of the proper relationship between people and their environment.

Because the personal values of the adopters are connected to the new technology during this stage, it is important for people to display the image they have adopted. This helps to explain the enthusiasm of these early adopters.

In the second stage of the adoption of a technology, the image has changed from a passive personal value to an active social value. The technology is no longer new, but is evaluated relative to the variety of available technologies displayed to consumers.

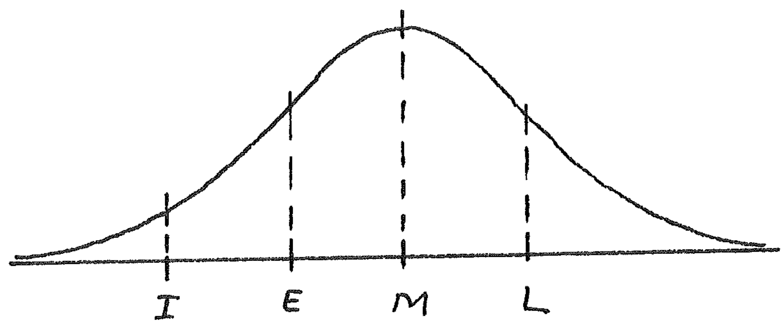
This transformation of the image changes the perceived attributes of the technology and the reasons used to justify its adoption. In the early stage, compatability of the technology with one's values is more important than the relative advantage of the new technology. In the second stage, relative advantage becomes more important. Economic and social status concerns change from risk taker and trend setter to economic rationality and fashion follower. Once this second stage is reached, the rate of adoption increases rapidly.

3.1.2 ASSUMPTIONS

Since the Arizona Department of Transportation is concerned about potential losses in revenue and the benefit in pollution reduction associated with alternative energy vehicles, this phase of the research effort focuses on identifying people most likely to adopt these technologies in addition to identifying the technologies most likely to be adopted. The "Innovators" and "Early Adopters" are assumed to be higher social status, more educated, have greater exposure or access to information and are more favorable to change or risk.

Thus, the early adopters are not representative of the normal population - rather, they are the "elite" of society. Therefore, the sampling techniques will analyze and compare demographic factors but no attempt will be made to achieve random sampling.

FIGURE 3.1



I	Innovators	2 %
E	Early Adopters	13 %
M	Majority	68%
L	Laggards	16%

Rogers, 1983. Diffusion of Innovations, (3rd Ed) New York: Free Press